HUMAN FACTORS ENGINEERING IN NAVY SYSTEMS ACQUISITION

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THESIS

HUMAN FACTORS ENGINEERING IN
NAVY SYSTEMS ACQUISITION

by

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The fact that human factors analysis has become one of the principal elements of systems engineering underscores its importance in systems acquisition management today. Therefore, instead of justifying the use of human factors in systems design, the authors will concentrate on presenting a method of human factors application that can be more gainfully employed in the acquisition of naval programs.

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Human Factors Engineering In

Navy Systems Acquisition

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ABSTRACT

The fact that human factors analysis has become one of the principal elements of systems engineering underscores its importance in systems acquisition management today. Therefore, instead of justifying the use of human factors in systems design, the authors will concentrate on presenting a method of human factors application that can be more gainfully employed in the acquisition of naval programs. Additionally, the authors will include in their analysis the depth of application of human factors engineering and when and where it should be applied in the development of a system.

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A. INTRODUCTION

The value of human factors engineering in system design has long been recognized and will not be debated in this thesis. An indication of its importance in Navy systems acquisition is evidenced in the Integrated Logistics Support (ILS) Guide (DOD 4100.35G). This guide presents a list of ten essential elements of ILS, foremost of which are maintainability, maintenance planning, personnel, and training, which comprise a large segment of human factors considerations. Kline (1970) has suggested that the importance of human factors engineering is underscored by its presentation as one of the essential elements of systems engineering. However, the actual application of, and dedication to the precepts in Navy systems acquisitions is taken as a matter of some concern. A primary question involves the stage at which Human Factors Engineering should be most manifest, and how can the degree of success of Human Factors programs be evaluated.

B. OPERATIONAL EVALUATIONS (OPEVALS)

An argument has been made that the emphasis for determining the extent of human-engineering-design efficiency should rest in Operational Evaluations (OPEVALS) of new systems. The concept of "proving worth" and the attitude of "take nothing for granted" are basic to operational evaluations

and to all field testing in general. Human Factors evaluations are the means by which the performance of hardware, procedures, and personnel are observed on a system to verify that the man-machine interfaces do what they are supposed to do (Meister & Rabideau, 1967). Operational evaluations as a specific form of field testing possess several advantages in contrast to laboratory evaluations. The first advantage is the degree of realism that can be brought to the test conditions since field tests may be the only way to answer certain questions about human behavior in real situations (Erdman & Neal, 1971). From a human factors standpoint, the completed, operational ship is an ideal test environment (as a result of the evaluation situation being completely "live") (Lazet & Walravon, 1971). The second advantage is in relation to the developmental process of a weapon system or support system where test tasks conducted toward the end of the developmental program generally better reflect the operational tasks being examined (i.e. the tests have better "content" validity) (Matheny, 1971).

Two principal disadvantages of conducting human factors tests or analyses during operational evaluations deal with controlling variables. First, the acceptability of tests directly depends on the extent to which duplicate data can be obtained from a repeat of the same tests (Meister, 1971). This implies that the same test conditions can be duplicated again and again which is not characteristic of operational testing. It is extremely difficult to repeat a

test under the same conditions a second time in a field test environment (Matheny, 1971). Therefore, the data obtained from operational evaluations is inferior in terms of precision and detail to that obtained from controlled testing and analytical studies.

The second disadvantage of conducting human factors analyses during operational evaluations is the measureability of variables in this operational setting. Results are meaningful only to the extent that the conditions which produced them are known, i.e. the identification of dependent and independent variables. For example, human errors are one of the most useful criteria in human factors research and yet are seldom measured during operational evaluations or any other types of field testing.

> "Errors resulting from lack of capability (e.g. deficient vision), training, skill, motivation, or fatigue would be categorized as operator-induced errors." (Meister, 1971).

It is generally acknowledged that the reason for this is the paucity of human errors, i.e. the trouble with error data is the low frequency of such data during test situations (Chapanis, 1962).

> "Without such data it is difficult to
> a) assess the importance of error in influencing equipment operations;
> b) pinpoint factors in system development which could be improved;
> c) predict the operational performance efficiency one can expect of a system, where that efficiency is influenced by personnel errors."
> (Meister, 1971).

Additionally, the limitations of obtaining error data during systems evaluations in the field are compounded by the small

number of opportunities to observe such data (Swain, 1969). Human error rates are on the order of .001 to .00003 for common industrial tasks (Rook, 1962).

Certainly, operational evaluations provide an opportunity to get the most effective indication of the success (or failure) of human-engineering-design effects. Perhaps the most potent argument against relying too heavily upon OPEVALS for human-factor analysis is the fact that effective, economical deficiency correction may not be feasible at that stage. Due to the complexity of man-machine interfaces and their functional inter-relationships in a completed weapon system, it is generally impossible to rectify human-engineering-design shortcomings without completely redesigning and reconforming the entire system. This is an impractical course of action when both time and money are considered in this post-development stage.

C. PROPER PHASING OF HUMAN FACTORS IN SYSTEM DEVELOPMENT

Therefore, the authors believe that human-factors considerations should be applied early in the design phase and conducted from that point on in the development of a system. Evaluation also should be a continuing process, and this requires application of criteria so that human-factors engineering can be monitored and controlled. The utilization of criteria in an evaluation is or should be an accepted concept. For even if criteria are assumed in some tacit manner, evaluation implies the comparison of values to some criteria or standard. From a practical standpoint, the difficulty arises

from the hierarchical nature of criteria. On the same system, one may measure system worth on the merits of its contributions to national defense and another may measure worth on the time required to repair the system. It seems to be a fact of criteria that the more specific, the more quantitative and the more defensible that a criterion is, the less it relates to the question of prime importance. The use of criteria in evaluations then is usually a matter of compromise. Two questions of prime importance that set forth the criteria for human factors are:

1) can the assigned personnel operate the equipment?

2) can the assigned personnel maintain the equipment?

Evaluations could be conducted at this level, with opinion as the criterion and testing consisting of merely asking the two questions. However, a test based on these two questions eliciting only opinions would be limited to subjective interpretations.

Three more defensible types of criteria have proven useful for human-factors questions. They are as follows: 1) relating human performance to system performance, 2) achieving consensus among system personnel, and 3) establishing human engineering design criteria. Hoisman and Daitch (1964) have suggested that the first of these is applicable in fortuitous situations and not as a standard approach because of the lack of usable methods for assessing human performance within the context of system effectiveness. The use of consensus among system personnel is a flexible criterion and

has been accepted as a standard approach; however, this approach demands the use of types of questionnaires which can create difficulties in obtaining objective, valid, and reliable data. The use of human-engineering-design criteria is an approach generally applicable to design, testing, and evaluation and has been accepted as a general approach.

The basic documentary guide to human engineering design criteria in Navy systems acquisitions is MIL-STD-1472A, <u>HUMAN ENGINEERING DESIGN CRITERIA FOR MILITARY SYSTEMS, EQUIPMENT AND FACILITIES</u>, the forward to which reads in part:

> "1. This standard establishes general human engineering criteria for development of Military systems, equipment and facilities. Its purpose is to present human engineering design criteria, principles and practices to be applied in the design of systems, equipment and facilities so as to:
>
> a. Achieve required performance by operator, control and maintenance personnel.
>
> b. Minimize skill and personnel requirements and training time.
>
> c. Achieve required reliability of personnel-equipment combinations.
>
> d. Foster design standardization within and among systems.
>
> 2. This standard does not alter requirements for system development participation of human engineering specialists to interpret and implement these practices and to provide solutions to human engineering problems which arise and which are not specifically covered herein."

In Chapter II this thesis will examine this document in detail, as well as MIL-H-46855A, which establishes the requirement for <u>applying</u> human engineering to Navy systems acquisitions. In addition, the required Human Engineering Program Plan, which is the tool for implementing human engineering requirements will be considered. Therefore,

Chapter II will be an overview of what is "laid on" a system from a human engineering aspect.

Chapter III examines the success of human engineering application in several Navy systems, relative to currently accepted Human Engineering thoughts as assimilated through readings indicated in the Bibliography.

In Chapter IV, an overview of some aspects of the acquisition process will be presented and recommendations made as to where and how human factors considerations may best be introduced.

Chapter V presents a summary of thesis conclusions and recommendations.

D. OBJECTIVES AND APPROACH

The primary questions addressed in the present thesis:

a) Are human factors adequately considered, carefully evaluated, and sufficiently and efficiently accounted for in all Navy systems?

b) At what stages of Navy Weapons System development should Human Factors Engineering be manifest, and how?

The method has been to assimilate current thoughts on human factors considerations, examine the requirements applied to Navy Weapons Systems, indicate that results have been unsatisfactory, and then review the Navy Weapons Acquisition cycle and include recommendations as to interfacing human factors considerations with the cycle to produce better results.

II. NAVY HUMAN FACTORS DIRECTIVES

The criteria and requirements for application of human engineering to Navy systems acquisitions are embodied in MIL-STD-1472A, Military Standard Human Engineering Design Criteria for Military Systems, Equipment and Facilities, and MIL-H-46855A, Military Specification Human Engineering Requirements for Military Systems, Equipment and Facilities. These documents firmly establish human engineering as a factor in systems acquisition.

As established in Chapter I, MIL-STD-1472A is the basic documentary guide to human engineering design criteria in Navy systems acquisitions. It establishes the base line design principles, limitations, and essentials requisite to achieve functional human engineering considerations in a system, equipment or facility. It might be looked at as the "nuts-and-bolts" document. MIL-H-46855A follows and consists of a directive for consideration and application of human engineering principles and criteria (especially noting those in MIL-STD-1472A) to Navy systems acquisitions. MIL-H-46855A is less specific than MIL-STD-1472A, and presents the concepts and precepts necessary for proper exercise of human factors considerations in systems, and mandates their application. The normal mechanism for implementing this mandate is the contractor's Human Engineering Plan. This chapter will be dedicated to consideration of each of these documents and plans.

A. MIL-STD-1472A

MIL-STD-1472A consists of a precise statement of the general human engineering criteria for development of military systems, subsystems, equipment and facilities, and presents the criteria, principles, and practices necessary to achieve mission success through integration of the human into the system and to achieve effectiveness, simplicity, efficiency, reliability, and safety of system operation, training, and maintenance.

The standard requires that military systems, equipment and facilities be designed to provide work environments which foster effective procedures, work patterns, and personnel safety, and which minimize discomfort, distraction and any other factors which degrade human performance or increase error potential. Design should also be directed toward minimizing personnel and training requirements within the limits of time, cost, and performance trade-offs.

The standard further requires that controls, displays, marking, coding, labeling, and arrangement schemes (equipment and panel layout) be uniform for common functions of all equipment.

The standard directs that the allocation of functions to personnel, equipment, and man-machine combinations be based on analysis and trade-off studies, including such considerations as: required sensitivity, precision, time, and safety; maximum reliability of system performance; minimum number of personnel and skills required to operate and maintain the system; and time-cost-performance.

More specifically, MIL-STD-1472A mandates that the design of military systems, equipment and facilities shall include consideration of human engineering, life support, and bio-medical factors that affect human performance, including:

a) Satisfactory atmospheric conditions including composition, pressure, temperature and humidity, including safeguards against uncontrolled variability beyond acceptable limits.

b) Safe range of acoustic noise, vibration, acceleration, shock, blast, and impact forces and safeguards against uncontrolled variability beyond safe limits.

c) Protection from thermal, toxicological, radiological, electromagnetic, pyrotechnic, visual, and other hazards.

d) Adequate space for man, his equipment, and free volume for the movements he is required to perform during operation and maintenance tasks under both normal and emergency conditions.

e) Adequate physical, visual and auditory links between men and their equipment under both normal and emergency conditions.

f) Efficient arrangement of operation and maintenance workplaces, equipment, controls, and displays.

g) Provisions for insuring safe, efficient task performance under reduced and elevated gravitational forces with safeguards against injury, equipment damage and disorientation.

h) Adequate natural or artificial illumination for operation, control, training, and maintenance.

i) Safe and adequate passageways, hatches, ladders, stairways, platforms, inclines, and other provisions for ingress, egress, and passage under normal, adverse and emergency conditions.

j) Provision of acceptable personnel accommodations including body support and restraint, seating, rest, and sustenance, i.e. oxygen, food, water, and waste management.

k) Provision of non-restrictive personal life support and protective equipment.

l) Provisions for minimizing psychophysiological stress, and fatigue.

m) Design features to assure rapidity, safety, ease and economy of maintenance in normal, adverse and emergency maintenance environments.

n) Satisfactory remote handling provisions and tools.

o) Adequate emergency systems for contingency management, escape, survival and rescue.

p) The clothing and personal equipment to be worn by personnel operating, riding in, or maintaining military systems or equipment must be considered in the design location and layout of workspaces, maintenance access, and passenger compartments. The restrictions imposed on human performance by clothing and personal equipment must also be considered in task allocation and control movements.

q) Information processing rates, decision-making effectiveness, etc.

It is also stated that equipment shall represent the simplest design consistent with functional requirements and expected service conditions, and that it shall be capable of operation, maintenance and repair by personnel with a minimum of training. In addition, a fail safe design will be provided in those areas where failure can disable the system or result in a catastrophe through damage to equipment, injury to personnel or inadvertent operation of critical equipment.

Another requirement of the standard is that the design of the system reflect the interaction requirements of crew served equipment. If more than one crew member must have simultaneous access to a particular group of controls or displays in order to insure proper functioning of a system, the operator assigned to control and monitor a particular function or group of related functions shall have at his disposal and within his reach and visual range, all controls and displays necessary to adequately fulfill his assignment.

MIL-STD-1472A also directs that consideration be given to safety factors, including minimization of potential human error in the operation and maintenance of the system, particularly under the conditions of alert or battle stress.

To expand on and delineate these general requirements, the major portion of the standard comprises a collection of detailed requirements. These definitized physical criteria

include standard dimensions, spatial interrelations, impress levels, etc. under such categories as Control-Display Integration, Visual Displays, Auditory Displays, Controls, Labeling, Anthropometry, Ground Workspace Design Requirements, Environment, Design for Maintainability, Design of Equipment for Remote Handling, Small systems and Equipment, Operational and Maintenance Ground Vehicles, and Hazards and Safety. Selected examples of these defined criteria and design limitations are exhibited in Appendix A.

As previously noted, the mandate for applying these criteria in Navy systems acquisitions is basically embodied in MIL-H-46855A, which points out the needs for human factors considerations and directs their inclusion in Navy systems acquisitions.

B. MIL-H-46855A

MIL-H-46855A establishes and defines the general requirements for applying the principles and criteria of human engineering to the development and acquisition of military systems, equipment and facilities. These requirements include the work to be accomplished or subcontracted by the contractor in effecting an integrated human engineering effort. Compliance with these requirements form the basis for including human engineering during proposal preparation and data reporting by the contractor (e.g. such items as flow charts, functional allocation tables, operational sequence diagrams, link analyses, and task descriptions). The specification directs that the principles and criteria of human

engineering shall be applied during development and acquisition of military systems, equipments and facilities to achieve the effective integration of man into the design of the system. Within the parameters established by system, equipment and facilities requirements, a human engineering effort should be provided to improve the man-machine interface and to achieve required effectiveness of human performance during system operation/maintenance/control and to make economical demands upon manpower resources, skills, training and costs. The human engineering effort should include active participation in three major interrelated areas of system development: 1) analysis, 2) design and development, and 3) test and evaluation.

1. Analysis

The purpose of analysis is to identify and define system, equipments and facilities operations, maintenance, training and control functions; to allocate these functions to man, equipment, or man and equipment; to analyze tasks derived from these functions; to develop human engineering design criteria, operation and maintenance procedures, and other requirements in the proper format and language for performance and design specifications and other documentation. Human engineering participation in analysis should begin with initial system planning and remain a significant element of the overall analysis effort. Analysis requirements should be incorporated as an integral element of the system engineering effort. Analytical parameters should be quantified,

where possible, and formed to permit cost-effectiveness studies of the man-machine interfaces and personnel participation in total system operation. The identification of human engineering high risk areas should be initiated as part of the analysis. The specification delineates specific areas wherein analysis shall include application of human engineering techniques. A synopsis of these areas follows.

a. Defining and Allocating System Functions

This involves analysis of the functions that must be performed by the system in achieving its objective. Human engineering principles and criteria should be applied to specify man-equipment performance requirements for system operation, maintenance and control functions and to allocate system functions to 1) automatic operation/maintenance, 2) manual operation/maintenance, or 3) some combination thereof. Analyses should be performed to determine basic information flow and processing required to accomplish the system objective and should include decisions and operations without reference to any specific machine implementation or level of human involvement. Plausible human roles (e.g. operator, maintainer, programmer, decision maker, communicator, monitor) in the system should be identified and estimates of processing capability in terms of load, accuracy, rate and time delay should be prepared for each potential operator/maintainer information processing function. (The initial use of these elements would be in determining allocation of functions, and then later refinement would permit use in definition of

information requirements and control, display and communication requirements.) Also useful would be an estimate of the effect on these capabilities likely to result from implementation or non-implementation of human engineering design recommendations. From projected performance data, cost data and known constraints, analyses and tradeoff studies should be conducted to determine which system functions should be machine-implemented and which should be reserved for the human operator/maintainer.

b. Equipment Identification

Human engineering principles and criteria should be applied along with all other design requirements to identify and select the equipment to be operated/maintained/controlled by man. MIL-H-46855A specifies that the "selected design criteria shall reflect human engineering inputs . . . to satisfy the functional and technical design requirements and to insure that the equipment will meet the applicable criteria contained in MIL-STD-1472."

c. Analysis of Tasks

Task analysis should provide one of the bases for making design decisions; e.g., determining before hardware fabrication whether system performance requirements can be met by combinations of anticipated equipment and personnel, and assuring that human performance requirements do not exceed human capabilities. Such analyses could also be used as basic information for developing preliminary manning levels, equipment procedures, and skill training and communication

requirements. Those gross tasks identified during human engineering analysis which are related to end items of equipment to be operated or maintained by man and which require critical human performance, reflect unsafe practices or are subject to promising improvements in operating efficiency should be further analyzed. Further analysis of critical tasks should identify: (1) the information required by man, including cues for task initiation; (2) information available to man; (3) evaluation process; (4) decision reached after evaluation; (5) action taken; (6) body movements required by action taken; (7) workspace envelope for man required by action taken; (8) workspace available; (9) location and condition of work environment; (10) frequency and tolerances of action; (11) time base; (12) feedback informing man of the adequacy of his actions; (13) tools and equipment required; (14) number of personnel required, their specialty and experience; (15) job aids or references required; (16) special hazards involved; (17) operator interaction where more than one crew member is involved; (18) operational limits of man (performance); and (19) operational limits of machine (state of the art). Such analysis should be performed for all affected missions and phases including degraded modes of operation. Individual and crew workload analysis should be performed and compared with performance criteria.

d. Preliminary System and Subsystem Design

Human engineering design principles and criteria should be applied to system and subsystem designs represented

by design criteria documents, performance specifications, drawings and data, such as functional flow diagrams, system and subsystem schematic block diagrams, interface control drawings, overall layout drawings and related applicable drawings provided in compliance with contract data requirements. The specification states that the "approval of those documents . . . shall signify that the system and subsystem configuration and arrangement satisfy man-equipment performance requirements and comply with applicable criteria specified in MIL-STD-1472."

2. Design and Development

The human engineering inputs derived from the foregoing analysis requirements, as well as other appropriate human engineering inputs should be converted into detail equipment design features during detail design of equipment. Human engineering provisions in the equipment should be evaluated for accuracy during design reviews. Experiments, laboratory tests (including dynamic simulation), and studies required to resolve human engineering and life support problems specific to the system should be conducted. Human engineering and life support problem areas should be noted and red-flagged, including the estimated effect on the system if the problem is not studied and resolved. Certainly, these experiments, laboratory tests, and studies should be conducted early enough that the results may be incorporated in equipment design. At the earliest practical point in the development program and well before fabrication of system

prototype, full-scale three-dimensional mockups of equipment involving critical human performance (such as an aircrew compartment, maintenance work shelter, or a command control console) should be constructed. The mockup should be sufficient to determine the adequacy of size, shape, arrangement, and panel content of the equipment for use by man. In some instances, scale models might be substituted for mockups. Such mockups and models provide a basis for resolving access, workspace and related human engineering problems, and incorporating solutions into system design. In addition, MIL-H-46855 specifies that in design area "where equipment involves critical human performance and where human performance measurements are necessary, functional mockups shall be provided" (emphasis added). Dynamic simulation techniques should also be utilized as a human engineering design tool when necessary for the detail design of equipment requiring critical human performance. Various models for the human operator, as well as man-in-the-loop simulation, should be considered. (While the simulation equipment may be intended for use as a design tool, its potential relationship to and use as training equipment should be a consideration in any plan for dynamic simulation.) Human engineering principles and criteria should be applied to equipment drawings during detailed design to assure that the equipment can be efficiently, reliably, and safely operated and maintained. All drawings depicting equipment important to system operation and maintenance by human operators should be included. Human engineering

principles and criteria should be applied to detailed design or work environments, crew stations, and facilities to be used by man in the system. MIL-H-46855 indicates that "approval of drawings, specifications and other documentation of work environment, crew stations and facilities . . . shall signify that human engineering requirements are incorporated therein and that the design complies with applicable criteria of MIL-STD-1472A." Since work environments, crew stations and facilities affect human performance under normal, unusual and emergency conditions, their design should encompass the following points:

a) Atmospheric conditions, such as composition, volume, pressure and control for decompression, temperature, humidity and air flow.

b) Weather and climate aspects, such as hail, snow, mud, arctic, desert and tropic conditions.

c) Range of accelerative forces, positive and negative, including linear, angular and radial.

d) Acoustic noise (steady state and impulse), vibration, and impact forces.

e) Provision for human performance during weightlessness.

f) Provision for minimizing disorientation.

g) Adequate space for man, his movement, and his equipment.

h) Adequate physical, visual, and auditory links between men and their equipment, including eye position in relation to display surfaces, control and external visual areas.

i) Safe and efficient walkways, stairways, platforms and inclines.

j) Provisions for minimizing psychophysiological stresses.

k) Provisions to minimize physical or emotional fatigue, or fatigue due to work-rest cycles.

l) Effects of clothing and personal equipment, such as full and partial pressure suits, fuel handler suits, body armor, polar clothing, and temperature regulated clothing.

m) Equipment handling provisions, including remote handling provisions and tools when material and environment require them.

n) Protection from chemical, biological, toxicological, radiological, electrical and electromagnetic hazards.

o) Optimum illumination commensurate with anticipated visual tasks.

p) Sustenance and storage requirements (i.e., oxygen, water and food), and provision for refuse management.

q) Crew safety protective restraints (shoulder, lap and leg restraint systems, inertia reels and similar items) in relation to mission phase and control and display utilization.

Based upon the human performance functions and tasks identified by human engineering analyses, human engineering principles and criteria should be applied to the development of procedures for operating, maintaining or otherwise using the system equipment. Such application should assure that

the human functions and tasks identified through human engineering analysis are organized and sequenced for efficiency, safety, and reliability and to assure that the results of this effort be reflected in the development of training and technical publications.

3. Test and Evaluation

As well as requiring that human engineering criteria and principles be applied to concept, design, and development, MIL-H-46855A directs that a human factors oriented test and evaluation program be established. Such programs would be conducted to: (1) assure fulfillment of applicable requirements; (2) demonstrate conformance of system, equipment and facility design to human engineering design criteria; (3) confirm compliance with performance requirements where man is a performance determinant; (4) secure quantitative measures of system performance which are a function of man-machine interaction; and (5) determine whether undesirable design or procedural features have been introduced. Human engineering testing should be incorporated into the normal test and evaluation program and integrated into engineering design tests, contractor demonstrations, R&D acceptance tests and other major development tests. Compliance with human engineering requirements should be tested as early as possible, and findings from early testing used in planning and conducting later tests. All failures occurring during, or as a result of, test and evaluation should be subjected to a human engineering review to differentiate between failures

due to equipment alone, man-equipment incompatibilities and those due to human error. The specification directs that human engineering portions of all tests include the following (as applicable):

a) A simulation (or actual conduct where possible) of mission or work cycle.

b) Tests in which participation is critical with respect to speed, accuracy, reliability or cost.

c) A representative sample of non-critical scheduled and unscheduled maintenance tasks.

d) Proposed job aids.

e) Utilization of personnel who are representative of the range of the intended military user population in terms of skills, size, and strength and wearing suitable military garments and equipment which are appropriate to the tasks.

f) Collection of task performance data.

g) Identification of discrepancies between required and obtained task performance.

h) Criteria for the acceptable performance of the test.

Although intended primarily for exploratory, advanced and engineering development, the specification might also be applied to other efforts. Compliance with the specification will provide assurance of positive management control of the human engineering effort required in the development and acquisition of military systems. Specifically, the specification is intended to assure that:

a) System requirements are achieved by appropriate use of the human component.

b) Through proper design of equipment and environment, the man-equipment combination performs within system tolerance limits.

c) Design features will not constitute a hazard to personnel.

d) Trade-off points between automated vs manual operation have been chosen for peak system efficiency within appropriate cost limits.

e) Human engineering applications are technically adequate.

f) The equipment is designed to facilitate required maintenance.

g) Procedures for operating and maintaining equipment are efficient, reliable and safe.

h) Potential error-inducing equipment design features are minimized.

i) The layout of the facility and the arrangement of equipment affords efficient communication and use.

j) The contractors provide the necessary manpower and technical capability to accomplish the forenoted objectives.

Hence, MIL-STD-1472A establishes the criteria for and MIL-H-46855A mandates the application of human engineering to Navy systems acquisitions. For most programs and on individual systems contracts, implementation of these requirements will be by way of the Human Engineering Program Plan.

The Human Engineering Program Plan, in accordance with the requirements of specifications, will be submitted as an identifiable and complete entity within the total system or equipment project proposal. The Plan will include a description of the tasks to be performed, human engineering milestones, methods to be used, design concepts to be utilized, test and evaluation program, and other data. The Human Engineering Program Plan will be the basis for contractual compliance. As stated in MIL-H-46855A, the Plan "shall describe an integrated effort within the total project; it shall provide specific information to show what tasks the contractor will do to meet specified human engineering requirements and when he will do these tasks."

C. HUMAN ENGINEERING PROGRAM PLAN

This plan is a contractor function, and provides a description of how the contractor will incorporate his human engineering effort into the system development and acquisition. This plan includes definition of human engineering tasks, task schedule, level of effort, documentation and reporting requirements, personnel qualification and assignment, and human engineering deliverable end items. This plan constitutes the implementing document for contractual compliance of human engineering efforts. It identifies human engineering tasks to be performed by the contractor and delineates contractor furnished human engineering data. The plan will be used as a basis for monitoring contractor progress and will also indicate any need for assistance and/or guidance from the service.

The Human Engineering Program Plan is further supported and expanded by several additional contractor-responsible plans, reports, and documents. Most pertinent of these are the Human Engineering Test Plan, Personnel Planning Information Report, Human Engineering Design Document, Human Engineering Maintenance/Accessibility Design Report, Task Analysis/Task Description Report, Human Engineering Progress Report, Human Engineering Test Report, and Human Engineering Final Report.

1. Human Engineering Test Plan

The Human Engineering Test Plan describes in detail the contractors proposed test and demonstration plan which will verify the man-equipment interface requirements for the operation and maintenance of the system. This plan delineates a detailed test program to be followed by the contractor and it is used to assure completeness of contractor's test program and conformance to contractual requirements. The plan shall be prepared for systematic and comprehensive testing necessary to verify that the system can be safely operated, maintained and supported by user personnel. It shall describe the approach(es) for obtaining data and shall establish and explain all standards, tests, associated analyses, and other means that will constitute adequate proof upon completion of the development phase that acceptable levels of human performance, time, accuracy and safety factors can be achieved in operational use under specified manning levels.

2. <u>Personnel Planning Information Report</u>

The Personnel Planning Information Report will be used by system engineers, human factors engineers, ILS managers, and others for planning purposes in order to develop needed manpower data so that total system manning and training estimates can be made. Personnel planning information will form the basis of the design approach for systems, equipment, and facilities. The definition of this personnel planning information is one of several system engineering techniques used to describe the system and major subsystems. The report will also be used by the Bureau of Naval Personnel for the new acquisition. It will be related to design work study inputs and used by the ILS Manager for the total Integrated Logistic System Program Plan.

3. <u>Human Engineering Design Document</u>

The Human Engineering Design Document describes the arrangement/layout and detail design of the crew station, crew station equipment and all other equipment having an interface with the human operator(s)/maintainer(s). It is used to: a) determine a technical approach to layout/arrangement/detail design of the crew station(s) and all equipment; b) evaluate layout/arrangement/detail design of crew station(s) and all equipment; and c) evaluate crew station ingress/egress if applicable.

4. <u>Human Engineering Maintenance/Accessibility Design Report</u>

The Human Engineering Maintenance/Accessibility Design Report describes accessibility to equipment for

purposes of replacement, inspection, servicing, adjustment, and calibration during preventive and corrective maintenance at the organizational level, the intermediate level, and the depot level. It delineates the human engineering effort applied to ensuring the accessibility of equipment.

5. Task Analysis/Task Description Report

The Task Analysis/Task Description Report describes the results of task analyses performed by the contractor and presents task descriptions. The purpose of the report is to summarize the work that the operator/maintainer performs and to provide a basis for the design of the system, equipment or facilities.

6. Human Engineering Progress Report

The Human Engineering Progress Report describes the status of the contractor's human engineering program. Each report is used to transmit human engineering progress, problems, and plans for each succeeding reporting period. These reports provide evidence that human engineering considerations are reflected in system design and development and indicate compliance with requirements for human engineering.

7. Human Engineering Test Report

The Human Engineering Test Report will be prepared following each major test, evaluation or demonstration and shall be submitted to provide evidence that the man-equipment interface requirements for the operation and maintenance of the system have been met.

8. Human Engineering Final Report

The Human Engineering Final Report summarizes contractor's human engineering efforts during design, development, verification, test and evaluation of the system, equipment, or facility. This report also documents decisions and trade-offs influencing design configuration. It identifies remaining human engineering problems, if any, and recommends remedial action. The report will be used to evaluate the contractor's human engineering efforts and to serve as a baseline for application to subsequent system improvements and future procurements.

These documents, then, provide the means of establishing and tracking the progress of human engineering considerations in an acquisition.

D. SUMMARY

It has been the intent of this section to establish the existence of requirements for, and mechanisms to sufficiently implement human engineering in systems acquisitions. The next logical step is to inquire if the procedures are applied. Are all our systems coming through the acquisition process with adequate human engineering? The next section examines that question, not exhaustively, but to an extent which may hopefully be at least indicative of the degree of success in human engineering application to Navy systems acquisitions.

III. ERROR CONSEQUENCES AND NAVY CASE STUDIES

A. ERRORS

Error as deviation from required performance is the main theme upon which human factors is centered. Errors occur because of inadequate considerations during the design and development stages of man-machine system (Meister, 1971).

B. HUMAN FACTORS

Meister (1971) has suggested that the reason human factors has evolved as a distinctive discipline is

> "....'good' design practice by which engineers mean the electronic, mechanical, etc. principles which they ordinarily apply to solve design problems will not be sufficient to deal with most human factors design problems. Solutions to these problems require a special way of analyzing equipment -- in terms of the effect of equipment upon the operator as well as the effect of the operator on the equipment -- and special techniques. This is why a distinctive discipline devoted to solving problems of this sort developed." (Meister, 1971).

To a large extent technology has outpaced the much needed considerations of human beings in systems design. Human factors engineers must work with other engineers from the outset of a project to ensure that the human being is an integral part of system design. For those individuals who operate systems with human factors design, there is a greater degree of job satisfaction and overall efficiency (Meister, 1971).

C. ERROR CONSEQUENCES

Human factors engineers key on understanding and eliminating operator error through modification of the human factors which produce it. The consequences of errors whether human, system, or equipment induced can be summarized as follows: (Meister, 1971)

1) accomplishment of the system function or goal is delayed
2) goal of the system cannot be carried out because of the operator's failure
3) equipment mission is not accomplished and the methods of carrying it out are temporarily lost
4) error which hazards the operators or others safety.

A large percentage of these errors will be eliminated or drastically reduced if human factors are considered from the outset of a project. If the man-machine interface is ignored in system design, the following consequences may occur during its development:

1) during the design phase -- inadequately designed equipment
2) during the production phase -- a) scrapped / reworked equipment, b) production delays, c) higher cost, d) malfunctioning equipment classified as functioning
3) during a system test phase -- a) delay in system operations, b) human-initiated malfunctions, c) system breakdown, d) failure to accomplish test, e) degradation in system performance, f) possible danger and loss of life

4) during the operation of a system -- a) delay in system operations, b) human-initiated malfunctions, c) system breakdown, d) failure to accomplish mission, e) degradation in system performance, f) possible danger and loss of life.

The intent of this chapter is to examine the success of human engineering programs in Navy systems, given the mechanisms, requirements, and specifications previously established in Chapter II. Are human factors adequately considered, carefully evaluated, and sufficiently and efficiently accounted for in all Navy systems? If the aforementioned criteria and procedures are sufficient and well implemented, the answer to the question should be easily demonstrated.

D. NAVY CASE STUDIES

Several programs are presented in summary form. The results are representative and are sufficient to indicate the lack of total success for human engineering efforts in Navy systems acquisitions.

1. <u>F-14</u>

The F-14 is a new supersonic fighter type of aircraft whose mission is fleet or air defense. The F-14 is designed to employ four types of armament: 1) guns or cannon, 2) two types of missiles and 3) conventional lay-down types of bombs.

The pilot's control stick has many functions in addition to attitude control, i.e. attitude trim, lateral trim, radio activation switch, weapons release, and weapons

selector. See Figure 1 on the following page for relative positions of additional controls, description of each, and how they are activated.

The pilot could inadvertently activate the wrong type of armament which could be disastrous to himself as well as to others in his flight. The pilot is already taxed to his limit with the other controls just from the mere number of motions and actions that his right hand is performing. To add a four-position lever type of switch to the simpler two-position switches enhances the possibility of selecting the wrong armament. Even though there is a "heads-up display" which spells out the armament selected, overloading of control requirements for the right hand combined with pilot stress or fatigue will eventually lead to accidents.

The Human Factors Guide (1972) points out several principles that this switch violates:

1) controls should be distributed so that no one limb is overburdened;

2) select, locate, and orient controls so that their motion is compatible with the movement of the associated display element, equipment component, or vehicle;

3) combine functionally related controls to reduce reaching movements. (Van Cott, 1972).

2. Planned Maintenance System (PMS)

One of the most common and flagrant categories wherein requirements are often engendered with an almost complete

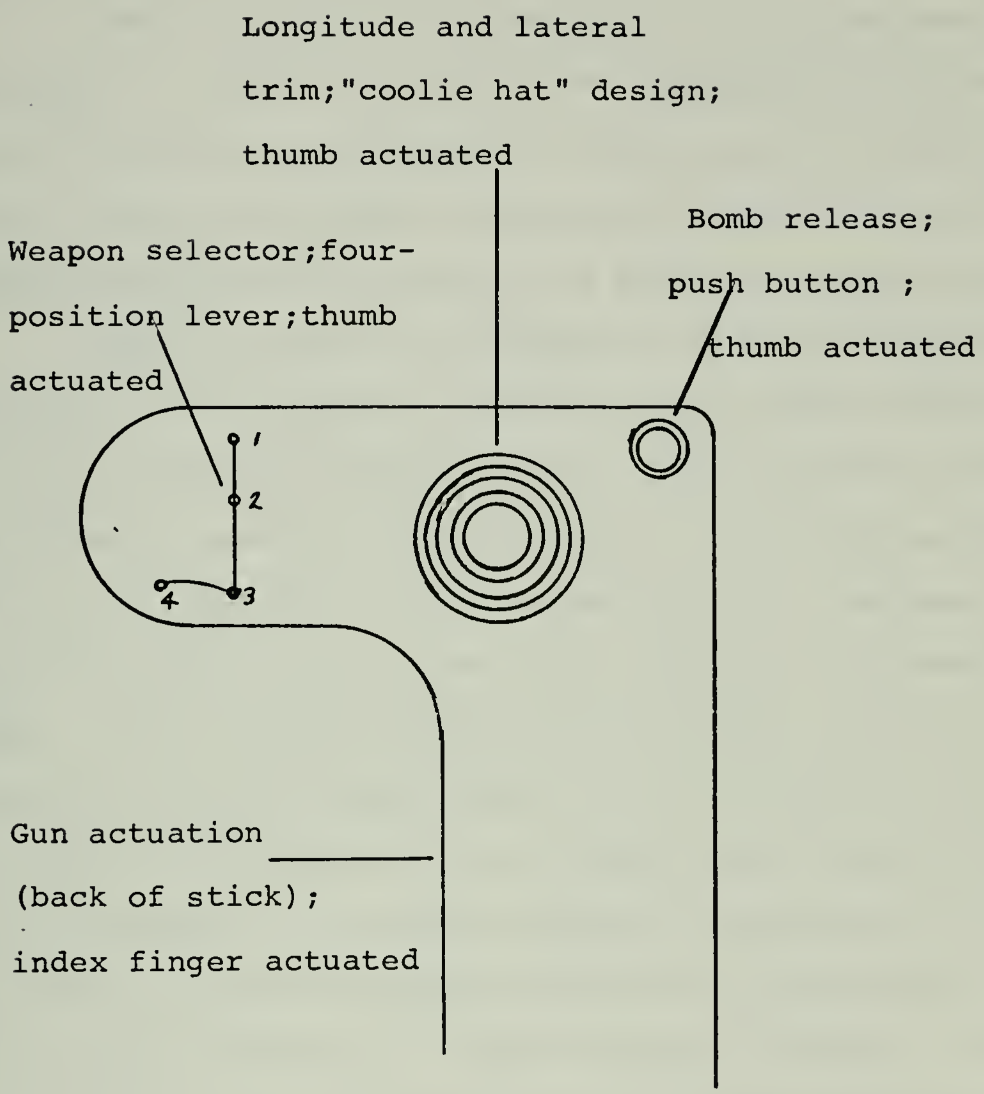


FIGURE 1 F-14 CONTROL STICK DIAGRAM

disregard for the total impact on human resources is the area of Planned Maintenance Systems (PMS).

PMS requirements are maintenance task analyses for individual hardware systems and are promulgated delineating actions required, periodicity of requirements, personnel required, and the man-hours that should be involved (given no complications) in performance of a given maintenance action.

The following is an example of how poorly manning resources and equipment requirements are jointly considered in establishing equipments, manning levels and maintenance requirements involved in a single ship. The Weapons Department of a diesel fast attack submarine had a complement of two Fire Control Technicians (FTs), and eight Torpedomen (TMs). The total PMS package for the Weapons Department (not including the Deck Force) would have required three FTs and six TMs for approximately twelve hours a day, seven days a week to perform the required preventive maintenance. This is without considering watch standing and trouble shooting requirements. This is an unsatisfactory workload, and evolved from ignoring the synergistic effect of compounding systems.

A human factors concern for the matching of manning resources with systems and systems maintenance requirements, all in view of mission requirements, should have been able to alleviate and rectify this situation, ensuring at least the minimal level of all considerations be met.

The task analysis required by MIL-H-46855A failed in allocating maintenance functions to man.

One weakness of the present procedure is that it is oriented toward the instant contract of a specific system (or, in most cases, subsystem) and may tend to fail when the integration of numerous such systems or subsystems is approached. The application of the ideas of Chapter IV should serve to avoid this problem.

3. AN-SPS-39 Radar

A DLGN 16 class ship had the SPS-39 radar, consisting of 13 electronic equipment cabinets, semi-permanently installed (i.e. bolted) along a wall in the electronic equipment room. This equipment is very susceptible to overheating, and the heat exchangers, fed off the ship's chill water system, were located in back of the equipment. To perform the requisite preventive maintenance on the heat exchangers, the equipment had to be dismantled and rolled out from the wall. This required the breaking of numerous electronic connections. Because of this, the equipment would be out of commission for long periods, and an extensive restart procedure involving numerous cold checks and double checks and requiring many man hours was required. This would not have had an enormous impact if done by Shipyard personnel during Shipyard availability, as was originally conceived. However, operating schedules, in conjunction with Planned Maintenance System (PMS) cyclic schedule, necessitated ships crew performance of the preventive maintenance action.

Careful human factors consideration during planning could have foreseen the operations demand and the infeasibility

of PMS support as planned. Also, realizing this infeasibility, the simple solution of making removable wall panels in the transverse aisle running behind the equipment could have mitigated the problem.

Several precepts of MIL-STD-1472A and MIL-H-46855A were violated or ignored in the configuration of this equipment:

1) The enjoinder to provide adequate space for man, his equipment, and free volume for the movements he is required to perform during operation and maintenance tasks.

2) The requirement for efficient arrangement of operation and maintenance workplaces, equipment, controls, and displays.

3) The proviso for design features to assure rapidity, safety, ease and economy of maintenance.

4) The call for minimization of potential human error in the operation and maintenance of the system.

The analysis failed in identifying and defining equipment maintenance functions and/or in allocating the functions to man.

Evaluation failed to disclose that the equipment and installation was <u>not</u> designed to facilitate required maintenance.

E. SUMMARY

The foregoing examination of human factors aspects in the Navy demonstrates that the human engineering efforts have not been as successful as should be. While these examples represent only a small sample, they are sufficient to illustrate the problem. The intent of this chapter was to indicate that human engineering in Navy systems acquisitions was a problem area that has not been solved. The next chapter will deal with possible reasons for the faults, and recommendations as to how human factors considerations may best be interrelated with the systems acquisition cycle to produce better results.

IV. RECOMMENDED HUMAN FACTORS INTERFACE WITH THE NAVY SYSTEM DEVELOPMENT CYCLE

Chapter III has indicated that human engineering in Navy weapons systems has not been as successful as might have been expected in spite of specifications which were deemed appropriate. Human factors are being omitted from weapon systems for two reasons: (1) the tendency to pay only "lip service" to the implementation of human factors requirements and (2) the uncoordinated timing and degree of human factors application in Navy weapon system development. One indication that "lip service" is being paid to systems is the fact that, in Fiscal Year 1972-1973, Naval Air Systems Command had 111 mishaps costing $1,671,000 which were directly attributable to human engineering design deficiencies (Sandler, 1974).

The major fault with human factors application in Navy weapon system development is the timing and degree of application of human factors criteria. This chapter considers aspects of Navy weapons development and establishes recommendations as to where and how human factors should be interfaced.

A NAVY SYSTEM DEVELOPMENT

The process by which a new Navy system is conceptualized and designed, or an existing system modified, is the Navy Weapons system development cycle. This cycle structures the development of complex systems from general requirements for

the particular system to the actual operation of system components. The cycle comprises an orderly progression of system definition, in an iterative fashion, through various phases of system development. The first three phases of the cycle are:

1) The Requirements Phase which establishes system requirements and constraints, conceives of alternate design approaches, and selects the optimum configuration.

2) The Conceptual Phase which details the techniques and technologies required to satisfy system requirements and evaluates the overall expected effectiveness of the system.

3) The Design and Advanced Development Phase which includes the determination of system specifications, operational and maintenance concepts, interfaces, and system support requirements.

Only these three phases will be described in the thesis since they structure the system, all subsequent phases being concerned with system fabrication, test, and implementation. Refer to figure 2, following page.

B. REQUIREMENTS PHASE

Successful accomplishments of complex naval weapons system development requires several interlocking phases. The first phase in the Navy's Weapons System Development Cycle, the Requirements Phase, broadly defines those capabilities that are required for successful military operations in the intermediate or distant future. Systems are envisioned

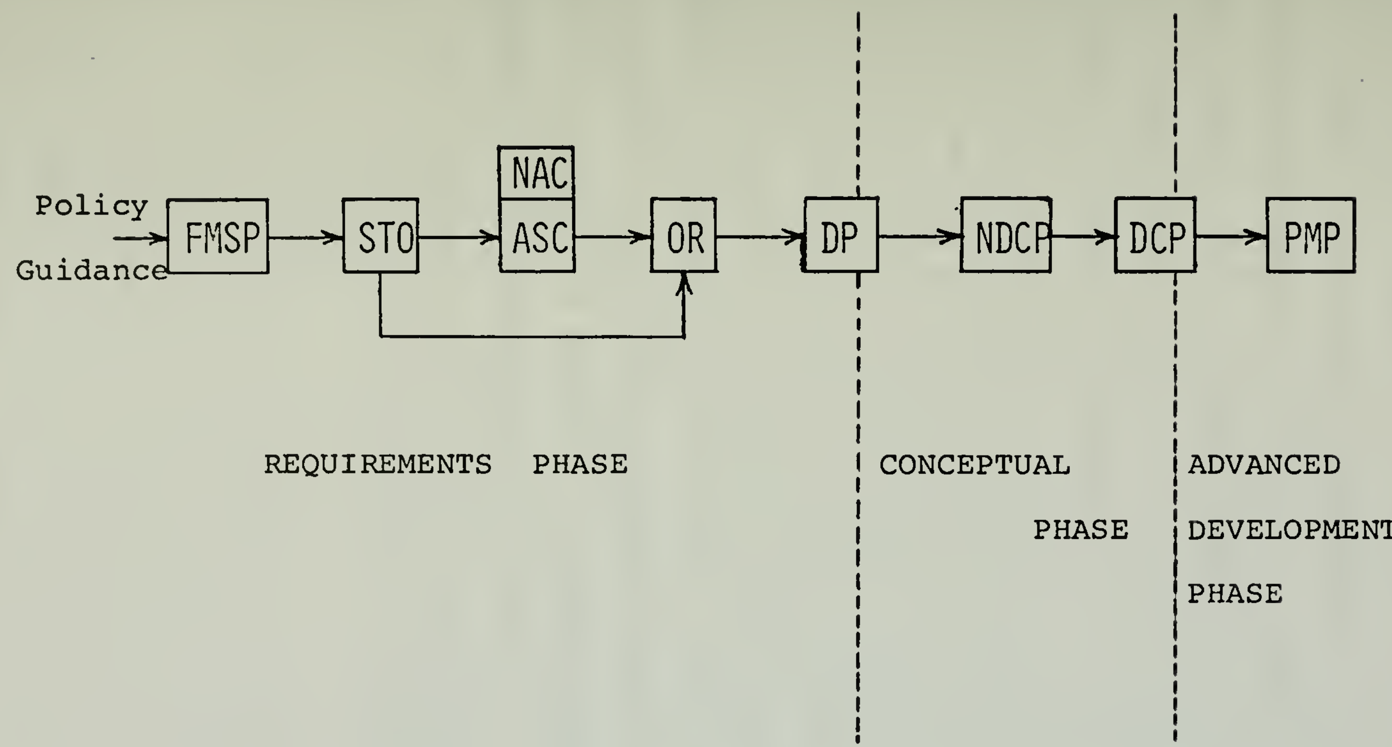


FIGURE 2 NAVY WEAPON SYSTEM DEVELOPMENT PROCESS

which define need capabilities to meet or surpass a possible threat or successfully complete a mission. These conceptual systems are refined by way of a developmental sequence which starts with a statement of general need and proceeds to a definition of a specific requirement. The next step is to develop approaches by which the capabilities may be acquired. For example, Navy planners define the threat posed to the fleet by enemy missiles as a sufficient distance to allow necessary defensive maneuvers. This threat potential might be further refined to a specific requirement for a new electronic warfare system which has the specific capabilities of detecting enemy missiles without compromising a ship's position, jamming the missile radar, warning other ships in the vicinity, and activating anti-missile missiles. The requirements, both general and specific, which might be considered a response to a mission analysis would be further developed into a conceptual system. Proposed approaches to feasible systems are developed which include:

1) Identification of the state-of-the-art technologies which would be potentially capable of producing such a system.
2) Development of operational requirements for the proposed system which include a full range of conditions under which the system might be required to operate.
3) Identification of alternative system configurations which would bring about the desired result.

In general, the above represents the procedure by which the Navy conceptually develops a new weapons system. These initial developments occur in an organized manner during the Requirements Phase.

Development of operational requirements includes four planning documents or phases: 1) the force and mission sponsor plan, 2) the science and technology objectives, 3) the advanced system concepts, and 4) the operational requirements.

1. Force and Mission Sponsor Plan (FMSP)

The FMSP represents the initial step in the Navy's Weapon System Development Cycle. It may state the need for a new weapon system or an improvement for an existing one. It defines what threats or missions are likely to exist and provides the Navy with an operational concept. The FMSP describes the Navy's requirements during a period of five to fifteen years in the future. It may be indefinite in the case of a completely new concept, or it may be well defined and specialized in the case of an improvement in an existing system. The FMSP may be developed as a result of several sources, such as:

a) an analysis of a possible threat;

b) an advance in technology; or

c) an output or by-product of another system.

No attempt is made to define or allocate constituent elements. In reality, the system does not yet exist, as minimum information requirements to initiate system design have not yet been conceived.

Human factors specialists have attempted to increase their contribution in this planning phase through development of Personnel Facts for Navy Planners (Whittenburg and Wise, 1966). This planning document would provide naval planners with a concise compilation of personnel data on the current midrange and long range naval manpower status.

2. Science and Technology Objectives (STO)

The STO describes in broad terms the Navy's needs and problems requiring research and development solutions, and are based on the Navy's role, objectives, and threat anticipated in the ten to twenty year future time frame. One STO is developed and maintained for each of the warfare or support areas shown under the following four Research, Development, Test, and Engineering (RDT&E) planning categories:

1) Strategic Deterrence
   a) Sea-based strategic warfare
2) Sea Control
   a) Anti-air warfare
   b) Anti-submarine warfare
   c) Anti-ship warfare
   d) Mine warfare or Mine countermeasures
3) Projection of Power Ashore
   a) Amphibious warfare
   b) Tactical warfare ashore
   c) Special warfare

4) Mission Support

a) Personnel/Medical

b) Support, logistics and underway replenishment

c) Ocean surveillance

d) Command, control, and communications

3. Advanced Systems Concepts (ASC)

The ASC provides methods for implementing the STO or FMSP. ASCs are arranged according to the fiscal year in which the system could be ready, from a technological standpoint, for initiation as an advanced development project. Each ASC will address a particular problem of, or an opportunity for a specific new capability for the Navy. Analysis and review result in possible solutions to the STO, which are documented by ASCs prepared by the various Systems Commands.

The human factors objectives during this planning phase are presented below. These objectives comprise the areas in which human factors specialists must be involved in the preparation of the development proposal.

a. Analyze the System Requirements

Requirements represent the system in its most basic form. This step translates mission requirements or objectives into system functional requirements. Ideally, the products of requirements analysis should be in measurable terms with specific tolerances and quantities. However, this goal frequently is not met, and definitive system outputs wait until feasibility of various proposed design

solutions has been explored. At this stage in the system development sequence, it is probably better not to make a decision concerning a particular solution but to recognize its utility in fashioning the eventual solution. At this point, hardware is not yet in the cycle. There must be additional iterations of the system and many design solutions before the hardware becomes operational.

Representative products of requirements analysis include:

1) organization of the system
2) system mission specification
3) identification of constraints imposed on the system

b. Analyze the System Functions that Can or Must Be Performed by Man

The purpose of this step in the development cycle is to decide when, where, and how men will be used in the system and what they will do. The success of this step often depends upon the information available concerning effective utilization of man, machine, and man-machine combinations. Categories of information required for functional allocations are therefore:

1) general capabilities of men
2) general capabilities of machines, and
3) general manner in which the man-machine will be interfaced.

Gross allocation of functions is accomplished through identification of all system operations, maintenance and support functions and their general sequences. A decision must then be made as to how man and machine may be utilized in a complementary manner to produce the desired outcome. An additional output of this effort is the provision of valuable inputs for personnel subsystem development concerning operation, maintenance, and support functions.

In order to assess the implications of these functions in terms of the number of personnel required, the capabilities that these personnel would be required to possess, and the training demands necessary to develop these capabilities; each function must be related to the Navy's abilities in personnel requirements.

4. Operational Requirement (OR)

The OR is a brief concise statement of operational needs, defined in the context of opposition forces and time frame limits. The operational problem set forth in the OR is to discuss the deficiency in present capability and consequences of not satisfying the operational problem. The concept behind the OR is for it to indicate compatability with other systems or forces, including U.S. Allies. This document further amplifies the operational problem with a statement concerning whether or not the employed system destroys, neutralizes, aborts or avoids threat. The OR also indicates any special logistic and training support considerations needed (OPNAVINST 5000.42).

The OR indicates, using current technological state-of-the-art or judgments for the threat period being considered, the criteria anticipated to be available for the OR system, component, or support system. These criteria may force some of the technological advances through a statement of the performance goals desired for the development to perform an intended mission. The OR should state an achievable level of performance below which the development will not be acceptable (floor) to preclude the expenditure of funds for marginal increases in capability. Additionally, the OR should include a statement of the desired performance level (ceiling) suitable to the operational requirements of the system in order to preclude the expenditure of funds for refinement in excess to operational needs (OPNAVINST 5000.42).

The major human factors project during this phase is to develop gross task data. These gross task data are produced as a further iteration of gross allocation of functions to man and machines. Even though a formal and detailed task analysis will not have been performed, gross task data will be produced.

Gross task analysis evaluates the major tasks required and emphasizes the display or situational features of behavior while the refined tasks analysis emphasizes the control or response behavior (Miller 1953). Information developed in this stage include the following:

a) tasks to be performed and sequence of tasks

b) display descriptions for information presentation

c) display critical values

d) decisions to be made in the operational sequence

e) major subtasks under each task

f) characteristic errors or possible malfunctions.

The information which has been developed during this phase provides information for technical development data banks, and also provides information for the human engineering design and personnel planning data banks.

C. THE CONCEPTUAL PHASE

During the Requirements Phase ideas for a system are set forth and analyzed and in the Conceptual Phase the formulated ideas are translated into proposals for system design and implementation.

The Conceptual Phase is initiated by the Navy Development Concept Paper (NDCP) and represents a further refinement of the system which was formulated in the Requirements Phase. In this phase a Development Proposal (DP) is used as a foundation for the NDCP. The DP summarizes the functions which must be performed to satisfy the broad requirements of the OR.

The Development Proposal describes alternative approaches investigated and includes relevant, previous test results. The proposal points out comparative advantages or disadvantages of each significant or reasonable alternative considered. The DP further describes logistic support approaches which identify significant impact on personnel skill levels and numbers.

The following information is included in the Development Proposal as applicable:

a) Estimated development cost and cost-time profile

b) Estimated unit cost of production model (design-to-cost)

c) Estimated development or production schedules

d) Indicate risks of failure with respect to performance, military value, cost and schedules

e) Indicate relation to "High-Low" mix and expected utilization in fleet modernization for future ship and aircraft classes, types, or models

f) Estimated degree of relative improvement over existing systems.

Additional factors which are to be considered in the Development Proposal are as follows:

a) logistics

b) training

c) environmental impact

d) human factors engineering

The Development Proposal formally responds to an Operational Requirement and is prepared through an informal dialogue between the sponsor and procuring activities.

The next step in the Conceptual Phase involves the Navy Development Concept Paper. The NDCP document defines program issues, considerations which support operational needs, program objectives, program plans, performance parameters, areas of risk, and development alternatives. The NDCP

supports and promulgates CNO decisions to initiate conceptual development programs and establish appropriate Advanced/ Engineering Development line items. The NDCP approval only authorizes extended systems planning and conceptual effort, within Navy authorization funding level as identified in the CNO approved program, and as ratified by ASN (R&D), until program initiation approval is received.

Activities which should be accomplished by human factors personnel during the NDCP formulation are as follows:

a) further refinement of the man-machine interfaces as more detailed information becomes available;

b) further refinement of the sequences of operations, maintenance functions and their interrelationships as more detailed information becomes available;

c) calculation of the gross external load and load-time phasing to be placed on the system. This activity includes the development of information to determine whether the system can be operated, maintained and supplied under all conditions. This is often accomplished by determining if the system will function under the worst possible conditions;

d) determination of preliminary manning estimates and organization structure. Preliminary manning estimates are a fairly late product in the system development cycle; however, the basis for specifying manning requirements extends back to the functional description of the system. Some of the other sources

of data for the preliminary manning estimates include the following:

1) Manning requirements for previously developed similar systems
2) Operational and maintenance concepts and gross task data
3) System design configuration
4) System operator or maintainer information and performance requirements;

e) provide preliminary training estimates;

f) identification of new Naval enlisted classification codes (NEC). Identification of new NECs represents a product of all the previous human factors information developed for the system. It is a result of comparing what might be described as a preliminary position descriptions with the current NEC descriptions. The analyst then determines whether the required positions are the same as existing positions.

D. ADVANCED DEVELOPMENT

Iterations of system development are continued and earlier steps are further refined. The system has already been proven to be feasible both technically and economically and attention is now directed toward detailed system design.

The system development objectives to be conducted in this phase include:

a) Preparation of electronic and mechanical design specifications for equipment;

b) Development of operational and maintenance concepts;

c) Establishment of interfaces between equipments, and the physical interfaces between personnel and equipment in terms of displays, controls, and communication requirements;

d) Selection or design of components for equipment production;

e) Development of Personnel Planning Information (PPI) concurrently with system design specifications;

f) Development of packaging specifications;

g) Fabrication of the prototype of initial configuration equipment;

h) Development of test and checkout requirements;

i) Development of logistic requirements;

j) Establishment of quality assurances and equipment modification programs;

k) Documentation of design specifications and technical manuals.

Human factors requirements during advanced development should include the following activities:

1) Evaluation of whether the system is operable.

2) Development of training plans. (Training plans encompass detailed definition of the methods to be utilized in accomplishment of all types of training necessary to operate, maintain, and support a new system.) This plan is required to ensure that a training project will provide sufficient trained personnel when the system becomes operational.

3) Refine training requirements. Training requirements are refined as further advanced information becomes available and additional design decisions are made.

4) Refine manning and selection requirements. Manning and selection requirements are refined as further advanced information becomes available and additional design decisions are made.

The majority of the advanced development phase is culminated in the Project Master Plan (PMP). This document provides uniform guidance for work planning and scheduling, and basic documentation which coordinates related command efforts for a specific project. The scope, depth, and detail of the planning effort required for a major project varies with the capability to be produced, its complexity, magnitude, and schedule. Guidance for the preparation of PMPs does not attempt to precisely prescribe the planning effort required for each individual project. Project managers are encouraged to remain flexible in tailoring the scope, depth, and detail of their planning efforts to suit the particular needs of the project development. The project manager must determine for his particular project the optimum depth and detail of planning needed.

E. SUMMARY

This chapter has presented recommendations for interfacing human factors with the Navy's current weapon-system-development cycle. Conclusions and recommendations are summarized in the following chapter.

V. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Requirements and directives for human factors in the Navy as presented in Chapter II are adequate and detailed guidelines, within the limit of their scope. However, as indicated in Chapter III, there is a lack of human factors considerations early in design development of Naval weapon systems. Chapter IV presented the proper phasing of human factors with the current Navy system development cycle. The authors are presenting the human factors interface with the Navy system development cycle as a summary of recommended actions to be taken at distinct stages in system development.

A. REQUIREMENTS PHASE

1. Force and Mission Sponsor Plan
   a. Human factors application through development of <u>Personnel Facts for Navy Planners</u> (Whittenburg and Wise, 1966)
2. Science and Technology Objectives
   a. Gathering possible human factors data for technology base
3. Advanced Systems Concepts
   a. Analyze system requirements
   b. Analyze system functions that can or must be performed by man
      (1) general capabilities of men
      (2) general capabilities of machines

(3) general manner in which the man-machine will be interfaced

4. Operation Requirement

a. Develop gross task data

(1) tasks to be performed and sequence of tasks

(2) display descriptions for information presentation

(3) display critical values

(4) decisions to be made in operational sequence

(5) major subtasks under each task

(6) characteristic errors or possible malfunctions

B. CONCEPTUAL PHASE

1. Development Proposal

a. Functions of the system spelled out

2. Naval Development Concept Paper

a. Further refinement of man-machine interfaces

b. Further refinement of sequences of operations

c. Calculation of the gross external load

d. Determination of preliminary manning estimates and organization structure

(1) manning requirements for previously developed similar systems

(2) operational and maintenance concepts and gross task data

(3) system design configuration

(4) system operator or maintainer information and performance requirements

e. Provide preliminary training estimates

f. Identification of new Naval enlisted classification codes (NEC)

C. ADVANCED DEVELOPMENT

1. Project Master Plan

a. Evaluation of whether the system is operable

b. Development of training plans

c. Refine training requirements

d. Refine manning and selection requirements

Human engineering in Navy systems acquisitions has not been as successful as it could be. The requirements are not really lacking, but the overall philosophy and imposition of human factors concerns on the system acquisition process is weak. A careful, considered input of human factors consideraions <u>throughout</u> a system's development is required to achieve the necessary human factors objectives.

APPENDIX A
EXCERPTS FROM MIL-STD-1472A,
SECTION 5: DETAILED REQUIREMENTS

5.2 VISUAL DISPLAYS -

5.2.1 General Visual displays should be utilized to provide the operator with a clear indication of equipment or system conditions for operation under any eventuality commensurate with the operational and maintenance philosophy of the system under design.

5.2.1.1 Display Illumination. - When the degree of dark adaptation required is not maximum, low brightness white light (preferably integral), adjustable as appropriate, shall be used; however, when the maximum degree of dark adaptation is required, low brightness red light (greater than 600 nm) shall be provided (nm = nanometers).

5.2.1.2 Information

5.2.1.2.1 Content. - The information displayed to an operator shall be limited to that which is necessary to perform specific actions or to make decisions.

5.2.1.2.2 Precision. - Information shall be displayed only to the degree of specificity and precision required for a specific operator action or decision.

5.2.1.2.3 Format. - Information shall be presented to the operator in a directly useable form. (Requirements for transposing, computing, interpolating, or mental translation into other units shall be avoided.)

5.2.1.2.4 Redundancy. - Redundancy in the display of information to a single operator shall be avoided unless it is required to achieve specified reliability.

5.2.1.2.5 Combined Information. - Information necessary for performing different activities (e.g., operation and troubleshooting) shall not simultaneously appear in a single display unless they are comparable functions requiring the same information.

5.2.1.2.6 Display Failure Clarity. - Displays shall be so designed that failure of the display or display circuit will be immediately apparent to the operator.

5.2.1.2.7 Display Circuit Failure. - Failure of the display circuit shall not cause a failure in the equipment associated with the display.

5.2.1.2.8 Unrelated Markings. - Trademarks and company names or other similar markings not related to the panel function shall not be displayed on the panel face.

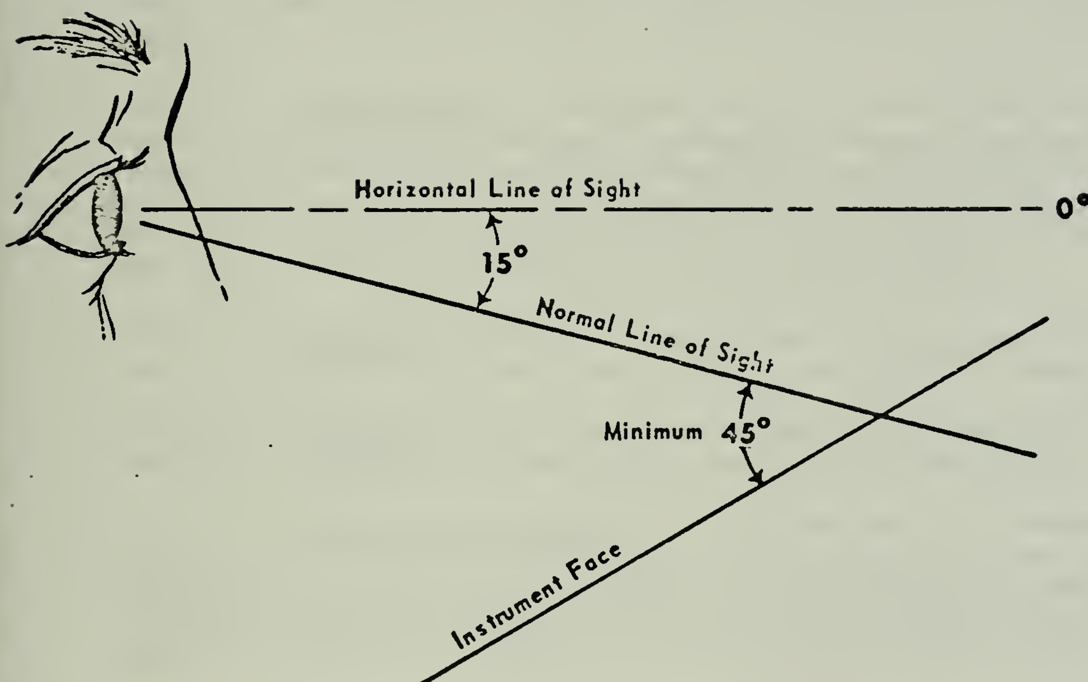


Figure 1. LINES OF SIGHT

5.2.1.3 Location and Arrangement.

5.2.1.3.1 Accuracy. - Displays shall be located and designed so that they may be read to the degree of accuracy required by personnel in the normal operating or servicing position.

5.2.1.3.2 Access. - Ladders, supplementary lighting, or other special equipment should not be required in order to gain access to or to read a display.

5.2.1.3.3 Orientation. - Display faces shall be perpendicular to the operator's normal line of sight whenever feasible and shall not be less than 45° from the normal line of sight (see Fig. 1). Parallax shall be minimized.

5.2.1.3.4 Reflectance. - Displays shall be constructed, arranged, and mounted to prevent reduction of information transfer due to the reflectance of the ambient illumination from the display cover. Reflection of instruments and consoles in windshields and other enclosures shall be avoided. If necessary, techniques (such as shields) shall be employed to insure that system performance will not be degraded.

5.2.1.3.5 Vibration. - Vibration of visual displays shall not degrade user performance below the level required for mission accomplishment.

5.2.1.3.6 Grouping. - All displays necessary to support an operator activity or sequence of activities, shall be grouped together.

5.2.1.3.7 Function and Sequence. - Displays shall be arranged in relation to one another according to their sequence of use or the functional relations of the components they represent. They shall be arranged in sequence within functional groups whenever possible to provide a viewing flow from left to right or top to bottom.

5.2.1.3.8 Frequency of Use. - Displays used most frequently should be grouped together and placed in the optimum visual zone (see Fig. 2).

5.2.1.3.9 Importance. - Very important or critical displays shall be placed in a privileged position in the optimum projected visual zone or otherwise highlighted.

5.2.1.3.10 Consistency. - The arrangement of displays shall be consistent in principle from application to application, within the limits specified herein.

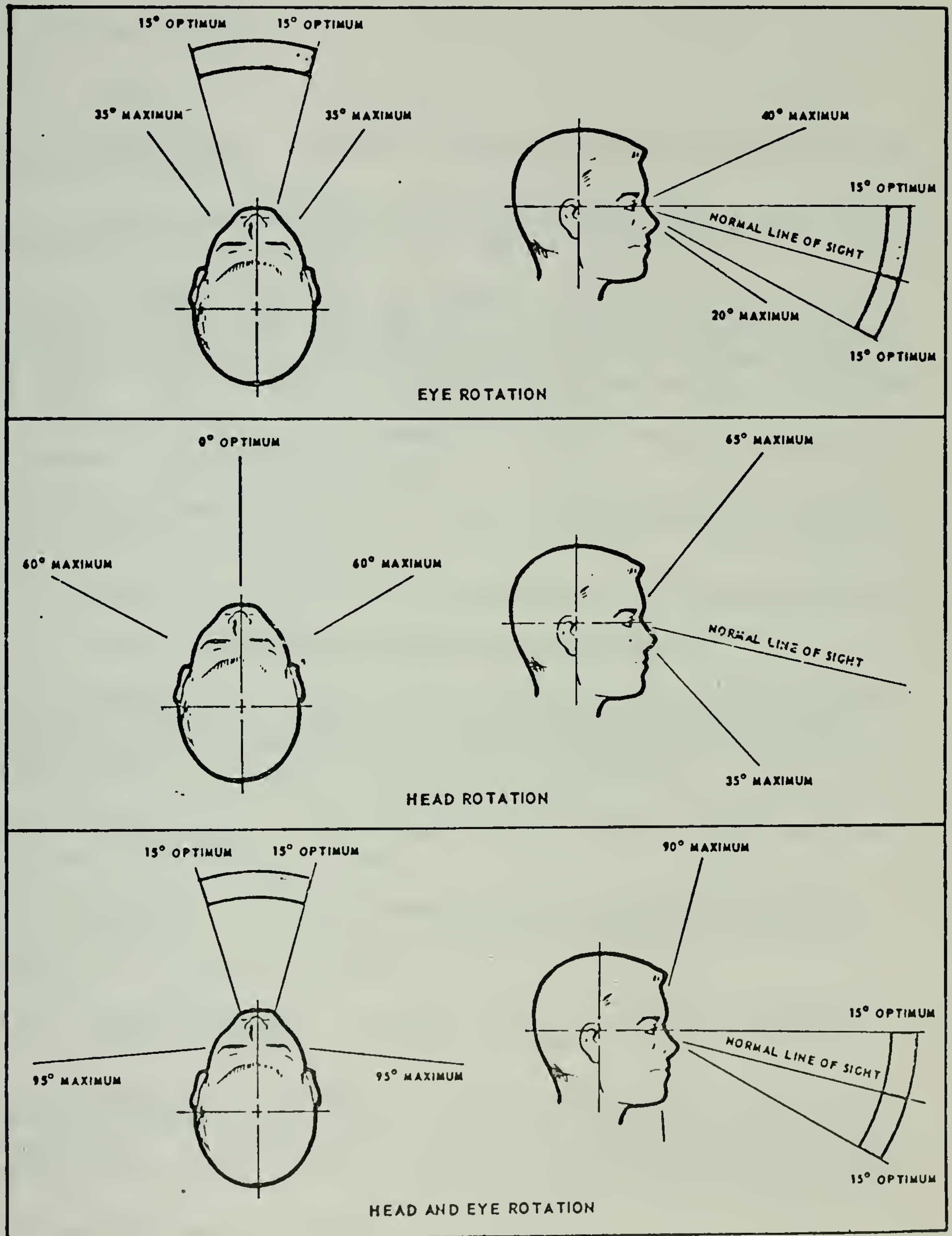


Figure 2. VERTICAL AND HORIZONTAL VISUAL FIELD

5.3 AUDITORY DISPLAYS -

5.3.1 General

5.3.1.1 Application. - Auditory displays should be provided under the following conditions:

a. The information that is to be processed is short, simple, and transitory requiring immediate or time-based response.

b. The common mode of visual display is restricted by overburdening; ambient light variability or limitation; operator mobility; degradation of vision by reason of vibration, high g-forces, hypoxia, other environmental considerations; or anticipated operator inattention.

c. The criticality of transmission response makes supplementary or redundant transmission desirable.

d. It is desirable to warn, alert, or cue the operator to subsequent additional response.

e. Custom or usage has created anticipation of auditory display.

f. Voice communication is necessary or desirable.

5.3.1.2 Signal Type. - Each situation requiring an auditory presentation shall be carefully evaluated to determine the optimum type of signal for that presentation, taking into consideration the criteria for different types of audio signals presented in Table III.

5.3.1.3 False Alarms. - The design of audio display devices and circuits shall preclude false alarms.

5.3.1.4 Failure. - The audio display device and circuit shall be designed to preclude warning signal failure in the event of system or equipment failure and vice versa.

5.3.1.5 Aircrew Stations. - Auditory signals for air crew stations shall conform to MIL-STD-411, where applicable.

5.3.1.6 Special Applications. - Auditory displays such as sonar and electronic counter measures shall be made compatible with the criteria stated herein. If system design precludes following such criteria, requirements for deviations shall be based upon the specific application.

5.3.2 Auditory Warning Devices

TABLE III. FUNCTIONAL EVALUATION OF AUDIO SIGNALS

FUNCTION	TYPE OF SIGNAL		
	TONES (Periodic)	COMPLEX SOUNDS (Non-Periodic)	SPEECH
QUANTITATIVE INDICATION	POOR Maximum of 5 to 6 tones absolutely recognizable.	POOR Interpolation between signals inaccurate.	GOOD Minimum time and error in obtaining exact value in terms compatible with response.
QUALITATIVE INDICATION	POOR-TO-FAIR Difficult to judge approximate value and direction of deviation from null setting unless presented in close temporal sequence.	POOR Difficult to judge approximate deviation from desired value.	GOOD Information concerning displacement, direction, and rate presented in form compatible with required response.
STATUS INDICATION	GOOD Start and stop timing. Continuous information where rate of change of input is low.	GOOD Especially suitable for irregularly occurring signals (e. g., alarm signals).	POOR Inefficient; more easily masked; problem of repeatability.
TRACKING	FAIR Null position easily monitored; problem of signal-response compatibility.	POOR Required qualitative indications difficult to provide.	GOOD Meaning intrinsic in signal.
GENERAL	Good for automatic communication of limited information. Meaning must be learned. Easily generated.	Some sounds available with common meaning (e. g., fire bell). Easily generated.	Most effective for rapid (but not automatic) communication of complex, multidimensional information. Meaning intrinsic in signal and context when standardized. Minimum of new learning required.

5.3.2.1 Warning Signals. - Audio signals should be provided as necessary to warn personnel of impending danger, to alert an operator to a critical change in system or equipment status, and to remind the operator of a critical action or actions that must be taken. NOTE: Certain audio signals have been standardized for aircraft use by joint service and international agreement. Stipulation of audio signals for future aircraft design should be in consonance with these agreements (see MIL-STD-411).

5.3.2.2 Nature of Signals. - Audio warning signals should normally consist of two elements: an alerting signal and an identifying or action signal.

5.3.2.2.1 Two-phase Signal. - When reaction time is critical and a two-phase signal is necessary, an alerting signal of 0.5 second duration shall be provided. All essential information shall be transmitted in the first 2.0 seconds of the identifying or action signal.

5.3.2.2.2 Single-phase Signal. - When reaction time is critical, signals shall be of short duration. If a single-phase signal is permissible, all essential information shall be tran [illegible]ted in the first 0.5 second.

5.3.2.3 Caution Signals. - Caution signals shall be readily distinguishable from warning signals and shall be used to indicate conditions requiring awareness but not necessarily immediate action.

5.3.2.4 Relation to Visual Displays. - When used in conjunction with visual displays, auditory warning devices shall be supplementary or supportive in nature. The auditory signal shall be used to alert and direct operator attention to the appropriate visual display.

5.3.2.5 Use With Several Displays. - One audio signal may be used in conjunction with several visual displays, provided that immediate discrimination is not critical to personnel safety or system performance.

5.3.2.6 False Alarms and Failures. - The design of audio-warning devices should minimize the possibility of false alarms. Circuitry shall be designed to preclude warning signal failure in the event of systems, equipment or power failure.

5.3.2.7 Circuit Test. - All audio-warning devices shall be equipped with circuitry test devices or other means of operability test.

5.3.3 Characteristics of Audio Warning Signals

5.3.3.1 Frequency

5.3.3.1.1 Range. - The major concentration of energy in audio warning devices shall be between 250 and 2,500 hertz, and the signal shall be identifiable on the basis of components below 2,000 hertz. The selection of the frequency band shall be in accordance with other criteria in this section.

5.3.3.1.2 Spurious Signals. - The frequency of a warning tone shall be different from that of the electric power employed in the system, to preclude the possibility that a minor equipment failure may generate a spurious signal.

5.3.3.2 Intensity

5.3.3.2.1 Compatibility With Acoustical Environment. - The intensity, duration and source location of aural alarms and signals shall be selected so as to be compatible with the acoustical environment of the intended receiver as well as the requirements of other personnel in the signal areas.

5.3.3.2.2 Maximum Sound Pressure Level. - The sound pressure level of the audio warning shall be at least 20 dB above the maximum anticipated ambient noise level at the frequencies of the warning signal but shall not exceed the maximum exposure levels specified in paragraph 5.8.3.1.

5.3.3.2.3 Use of Headsets. - Where the ambient noise level will exceed 100 dB, audio warning signals shall be presented through the operator's headset.

5.3.3.2.4 Discomfort. - Audio warning signals should not be of such intensity as to cause discomfort or "ringing" in the ears as an after-effect.

5.3.4 Signal Characteristics in Relation to Operational Conditions and Objectives

5.3.4.1 Audibility. - Where audibility is a critical factor, a signal-to-noise ratio of approximately 10 dB at the audible frequency band in which the background noise is lowest shall be provided.

5.3.4.2 Alerting Capability

5.3.4.2.1 Attention. - Signals with high alerting capacity should be provided when the system or equipment imposes a requirement on the operator for concentration of attention. Such signals shall not, however, be so startling as to preclude appropriate responses or interfere with other functions by insistently holding attention away from other critical signals.

5.3.4.2.2 Onset and Sound Pressure Level. - The onset of critical alerting signals should be sudden, and relatively high sound pressure level should be provided within the maximum sound pressure level limits specified herein.

5.3.4.2.3 Dichotic Presentation. - When earphones will be worn in the operational situation, a dichotic presentation should be used whenever feasible, alternating the signal from one ear to the other by means of a dual-channel headset.

5.3.4.2.4 Headset. - When the operator will wear earphones covering both ears during normal equipment operation, the auditory warning signal shall be directed to the operator's headset as well as to the work area.

5.3.4.3 Discriminability

5.3.4.3.1 Use of Different Characteristics. - When several different auditory signals are to be used to alert an operator to different types of conditions, discriminable difference in intensity, pitch, or use of beats and harmonics shall be provided. If absolute discrimination is required, the number of signals to be identified shall not exceed four.

5.3.4.3.2 Coding. - Where discrimination of warning signals will be critical to personnel safety or system performance, audio signals shall be appropriately coded. Alarms that are perceptibly different shall be selected to correspond with different conditions requiring critically different operator responses (e.g., maintenance, emergency conditions, and health hazards). Such signals shall be sufficiently different to minimize the operator's search of visual displays.

5.3.4.3.3 Critical Signals. - The first 0.5 second of a fast reaction audio signal shall be discriminable from the first 0.5 second of any other signal that may occur. Familiar signals with established names or associations shall be selected. Speech should be used whenever feasible.

5.3.4.3.4 Action Segment. - The identifying or action segment of an audio warning signal shall specify precisely the emergency or any other conditions requiring actions.

5.3.4.3.5 Differentiation From Routine Signals. - Aural alarms intended to bring the operator's attention to a malfunction or failure shall be differentiated from routine signals such as bells, buzzers, and normal operation noises.

5.3.4.3.6 Prohibited Types of Signals. - The following types of signals shall not be used as warning devices where possible confusion might exist because of the operational environment.

a. Modulated or interrupted tones that resemble navigation signals or coded radio transmissions

b. Steady signals that resemble noises, static, or sporadic radio signals

c. Trains of impulses that resemble electrical interference whether regularly or irregularly spaced in time

d. Simple glissandi which may be confused with the type made by two carriers when one is being shifted in frequency (beat-frequency-oscillator effect)

e. Scrambled speech effects that may be confused with cross modulation signals from adjacent channels

f. Signals that resemble random noise, periodic pulses, steady or frequency modulated simple tones, or any other signals generated by standard countermeasure devices (e.g., "bagpipes").

g. Signals similar to random noise generated by air conditioning or any other equipment

h. Signals that resemble sounds likely to occur accidently under operational conditions.

5.3.4.4 Compatibility

5.3.4.4.1 Existing Signals. - The meaning of audio warning signals selected for a system shall be consistent with warning signal meanings already established for that function.

5.3.4.4.2 Acoustic Environment. - Established signals shall be used, provided they are compatible with the acoustic environment and the requirements specified herein for the voice communication system. Standard signals shall not be used to convey new meanings.

5.3.4.5 Masking

5.3.4.5.1 Other Critical Channels. - Audio warning signals shall not interfere with any other critical functions or warning signals, or mask any other critical auditory signals.

5.3.4.5.2 Separate Channels. - Where a warning signal delivered to a headset might mask another essential auditory signal, separate channels may be provided to direct the warning signal to one ear and the other essential auditory signal to the other ear. In such a situation and when required by operating conditions, this dichotic presentation may further provide for alternation of the two signals from ear to ear.

5.4 CONTROLS -

5.4.1 General Criteria

5.4.1.1 Selection

5.4.1.1.1 Distribution of Load. - Controls shall be selected and distributed so that none of the operator's limbs will be overburdened.

5.4.1.1.2 G-loading. - Where applicable, control selection shall include consideration of operation under variable g-loading on the operator.

5.4.1.1.3 Multirotation Controls. - Multirotation controls shall be used when precision is required over a wide range of adjustment.

5.4.1.1.4 Detent Controls. - Detent controls shall be selected whenever the operational mode requires control operation in discrete steps.

5.4.1.2 Direction of Movement

5.4.1.2.1 Consistency of Movement. - Controls shall be selected so that the direction of movements of the control will be consistent with the related movement of an associated display, equipment component, or vehicle. In general, movement of a control forward, clockwise, to the right, or up or pressing or squeezing a control shall turn the equipment or component on, cause the quantity to increase, or cause the equipment or component to move forward, clockwise, to the right, or up. Valve controls are excepted (see 5.4.1.2.4).

5.4.1.2.2 Multidimensional Operation. - When the vehicle, the equipment, or the components are capable of motion in more than two dimensions, exception to 5.4.1.2.1 shall be made if necessary to ensure consistency of anticipated response (e.g., forward motion of a directional control causes some vehicles to dive or otherwise descend rather than to simply move forward). When several controls are combined in one control device, caution shall be exercised to avoid conflicts (e.g., control motion to the right is compatible with clockwise roll, right turn, and direct movement to the right).

5.4.1.2.3 Operator-control Orientation. - Controls shall be oriented with respect to the operator. Where the operator may use two or more vehicle operator stations, the controls shall cause movement oriented to the operator at the effecting station, provided remote visual reference is not used.

5.4.1.2.4 Valve Controls. - Rotary valve controls should open the valve with a counter clockwise motion. Valve controls shall be provided with double-ended arrows showing the direction of operations and appropriately labeled at each end to indicate the functional result (e.g., open and close).

5.4.1.3 Arrangement and Grouping

5.4.1.3.1 Grouping. - All controls which have sequential relations, which have to do with a particular function of operation, or which are operated together shall be grouped together along with their associated displays. When several steps of a sequence are combined on one control, the control movements required shall be minimized and the systems shall not be cycled ON/OFF or through operational modes unnecessarily.

5.4.1.3.2 Sequential Operation. - Where sequential operations follow a fixed pattern, controls shall be arranged to facilitate operation, (e.g., in a pattern left-to-right and top-to-bottom, as a printed page).

5.4.1.3.3 Location of Primary Controls. - The most important and frequently used controls shall have the most favorable position with respect to ease of reaching and grasping (particularly rotary controls and those requiring fine settings).

5.4.1.3.4 Consistency. - The arrangement of functionally similar, or identical, primary controls shall be consistent from panel to panel throughout the system, equipment, unit, or vehicle.

5.4.1.3.5 Remote Controls. - Where controls are operated at a position remote from the display, equipment, or vehicle controlled, control arrangement shall be established to facilitate direction-of-movement consistency. The observed result and not the effecting mode shall be considered.

5.3.1.3.6 Maintenance and Adjustment. - In general, controls used solely for maintenance and adjustment and referred to infrequently, shall be covered during normal equipment operation, but shall be readily accessible and visible to the maintenance technician when required.

5.4.1.4 Coding

5.4.1.4.1 Methods and Requirements. - The selection of a coding mode (e.g., size and color) for a particular application shall be determined by the relative advantages and disadvantages for each type of coding. Where coding is selected for the purpose of differentiating among controls, application of the code shall be uniform throughout the system. (see Table IV for advantages and disadvantages)

TABLE IV. ADVANTAGES AND DISADVANTAGES OF VARIOUS TYPES OF CODING

ADVANTAGES	TYPE OF CODING					
	LOCATION	SHAPE	SIZE	MODE OF OPERATION	LABELING	COLOR
Improves visual identification.	X	X	X		X	X
Improves nonvisual identification (tactual and kinesthetic).	X	X	X	X		
Helps standardization.	X	X	X	X	X	X
Aids identification under low levels of illumination and colored lighting.	X	X	X	X	(When trans-illuminated)	(When trans-illuminated)
May aid in identifying control position (settings).		X		X	X	
Requires little (if any) training; is not subject to forgetting.					X	
DISADVANTAGES						
May require extra space.	X	X	X	X	X	
Affects manipulation of the control (ease of use).	X	X	X	X		
Limited in number of available coding categories.	X	X	X	X		X
May be less effective if operator wears gloves.		X	X	X		
Controls must be viewed (i.e., must be within visual areas and with adequate illumination present).					X	X

5.4.1.4.2 Location-Coding. - Controls associated with similar functions should be in the same relative location from panel to panel.

5.4.1.4.3 Size-Coding. - No more than three different sizes of controls shall be used in coding controls for discrimination by absolute size. Controls used for performing the same function on different items or equipment shall be the same size.

5.4.1.4.4 Shape-Coding. - Control shapes shall be both visually and tactually identifiable and shall be designed to be free of sharp edges.

5.4.1.4.5 Color-Coding

5.4.1.4.5.1 Choice of Colors. - Controls shall be black (17038) or gray (26231). If color coding is required, only the following colors identified in FED-STD-595 shall be selected for control coding.

a. Red, 11105

b. Green, 14187

c. Orange-Yellow, 13538

d. White, 17875

e. Blue, 15123, shall be used if an additional color is absolutely necessary.

5.4.1.4.5.2 Immediate Action Controls. - Immediate action controls for aircraft shall conform to MIL-M-18012.

5.4.1.4.5.3 Relation to Display. - When color-coding must be used to relate a control to its corresponding display, the same color shall be used for both the control and the display.

5.4.1.4.5.4 Control Panel Contrast. - The color of the control shall provide contrast between the panel background and the control.

5.4.1.4.5.5 Ambient Lighting and Color-coding Exclusion. - Prior to selection of color code, consideration shall be given to anticipated ambient lighting co-ordination throughout the mission. Color-coding shall not be used as a primary identification medium if the spectral characteristics of ambient light during the mission, or the operator's adaptation to that light, varies as the result of such factors as solar glare, filtration of light, and variation from natural to artificial light. If red lighting is to be used during a portion of the mission, controls which would otherwise be coded red shall be coded by orange-yellow and black striping.

5.4.1.4.5.6 Labeling of Controls. - Control labeling shall conform to the criteria in paragraph 5.5.

5.4.1.5 Compatibility with Handwear. - Controls shall be compatible with handwear to be utilized in the anticipated environment. All dimensions cited herein are for bare hands and should be revised where necessary for use with gloves or mittens.

5.4.1.6 Blind Operation. - Where "blind" operation is necessary the controls shall be shape-coded, or separated from adjacent controls by at least 5 inches (12.7cm).

5.4.1.7 Prevention of Accidental Activation

5.4.1.7.1 Location and Design. - Controls shall be designed and located so that they are not susceptible to being moved accidentally. Particular attention shall be given to critical controls whose inadvertent operation might cause damage to equipment, injury to personnel or degradation of system functions.

5.4.1.7.2 Internal Controls. - Internal or hidden controls should be protected, because it is usually not obvious that such controls have been disturbed and it may be difficult and time consuming to locate and readjust them.

5.4.1.7.3 Rapid Operation. - Any method of protecting a control from inadvertent operation shall not preclude its being operated within the time required.

5.4.1.7.4 Methods. - For situations in which controls must be protected from accidental activation, one or more of the following methods, as applicable, shall be used:

a. Locate and orient the controls so that the operator is not likely to strike or move them accidentally in the normal sequence of control movements.

b. Recess, shield, or otherwise surround the controls by physical barriers. The control shall be entirely contained within the envelope described by the recess or barrier.

c. Cover or guard the controls.

d. Provide the controls with interlocks so that extra movement (e.g., a side movement out of a detent position or a pull-to-engage clutch) or the prior operation of a related or locking control is required.

e. Provide the controls with resistance (i.e., viscous or coulomb friction, spring-loading, or inertia) so that definite or sustained effort is required for actuation.

f. Provide the controls with a lock to prevent the control from passing through a position without delay when strict sequential activation is necessary (i.e., the control moved only to the next position, then delayed).

g. Design the controls for operation by rotary action.

5.4.1.7.5 Dead Man Controls. - "Dead man" controls, which will result in system shut-down to a non-critical operating state when force is removed, shall be utilized wherever operator incapacity can produce a critical system condition.

5.4.2 Rotary Controls

5.4.2.1 Discrete Rotary Selector Switches

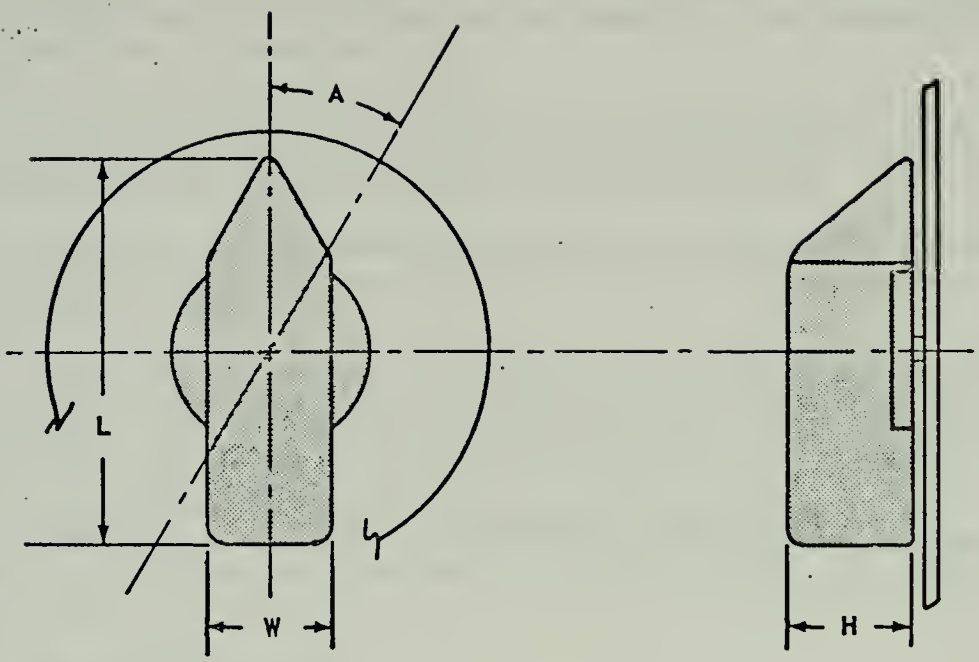
5.4.2.1.1 Application. - Rotary selector switches should be used for discrete function when three or more detented positions are required. Rotary selector switches should not be used for a two-position function unless ready visual identification of control position is of primary importance and speed of control operation is not critical.

5.4.2.1.2 Moving Pointer. - Rotary selector switches should be designed with a moving pointer and a fixed scale.

5.4.2.1.3 Shape. - Moving pointer knobs shall be bar shaped, with parallel sides, and the index end shall be tapered to a point. Exceptions may be justified when pointer knobs are shape-coded when space is restricted and torque is light. Shape-coding shall be used when a group of rotary controls, used for widely different functions, are placed on the same panel and control confusion might otherwise result.

5.4.2.1.4 Positions. - A rotary selector switch which is not visible to the operator during normal system operation shall have no more than 12 positions and rotary selector switches that are constantly visible to the operator shall have not more than 24 positions. In addition, the following criteria shall apply.

a. Where possible, rotary switch positions shall not be placed directly opposite each other, in order to reduce confusion as to which end of the knob is the pointer.



	DIMENSIONS			RESISTANCE
	L Length	W Width	H Depth	
Minimum	1.0"	-	0.625"	1 in-lb
Maximum	4.0"	1.0"	3.0"	6 in-lb

	DISPLACEMENT A		SEPARATION	
	*	**	One-Hand Random	Two-Hand Operation
Minimum	15 deg	30 deg	1"	3"
Maximum	40 deg	90 deg	-	-
Preferred	-	-	2"	5"

* For facilitating performance
** When special engineering is required

Figure 3. ROTARY SELECTOR SWITCH

b. Stops shall be provided at the beginning and end of the range of control positions if the switch is not required to be operated beyond the end positions or specified limits.

c. The switch resistance shall be elastic, building up, then decreasing as each position is approached, so that the control snaps into position without stopping between adjacent positions.

5.4.2.1.5 Contrast. - A reference line shall be provided on rotary switch controls. This line shall have at least 50 percent contrast with the control color.

5.4.2.1.6 Parallax. - The pointer knob shall be mounted sufficiently close to its scale to minimize parallax between the pointer and the scale markings. When viewed from the normal operator's position, the parallax error shall not exceed 25% of the distance between scale markings.

5.4.2.1.7 Dimensions, Resistance, Displacement, and Separation. - Control dimensions, resistance, displacement, and separation between adjacent edges of areas swept by rotary selector switches should conform to the criteria in Figure 3.

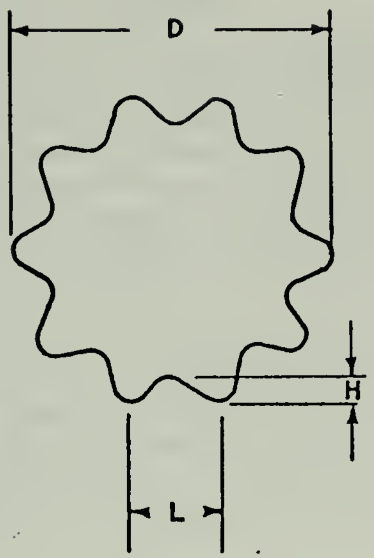
5.4.2.2 Thumbwheel Controls

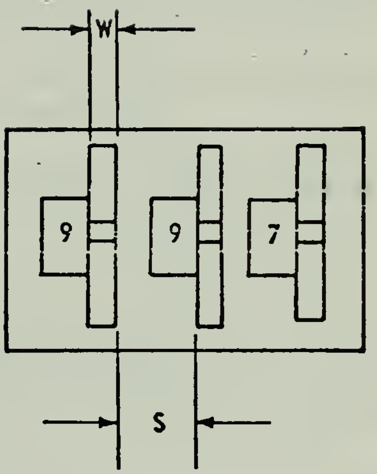
5.4.2.2.1 Application. - Thumbwheel controls may be used if the function requires a compact digital control-input device (for a series of numbers) and a readout of these manual inputs for verification. The use of thumbwheels for any other purposes is discouraged. Thumbwheels may be either discrete or continuous as applicable. Detent indexing units should provide 10 positions (0 - 9) in digital or binary (3 or 4 bits and complement) outputs.

5.4.2.2.2 Shape. - Each position around the circumference of a discrete thumbwheel shall have a slightly concave surface or shall be separated by a high-friction area which is raised from the periphery of the thumbwheel. Continuous thumbwheels shall employ high friction raised areas to facilitate movement.

5.4.2.2.3 Coding. - Thumbwheel controls may be coded by location, labeling, and color (e.g., reversing the colors of the least significant digit wheel as on typical odometers). Where used as input devices, thumbwheel switch OFF or NORMAL positions should be color coded to permit a rapid check that a great number of digits have been reset to their normal position.

5.4.2.2.4 Direction of Movement. - Direction of movement shall be compatible with the criteria set forth in 5.1.3.12.





	D DIAMETER (in.)	L TROUGH DISTANCE (in.)	W WIDTH (in.)	H DEPTH (in.)	S SEPARATION (in.)	RESISTANCE (in. – lb)
Minimum	1.5	0.45	0.1	1/8	0.4	1
Maximum	2.5			1/2		3

Figure 4. DISCRETE THUMBWHEEL CONTROL

5.4.2.2.5 Numerals

5.4.2.2.5.1 Internal Illumination. - For areas in which ambient illumination will provide display brightness below 1 Ft-L, the thumbwheel shall be internally illuminated. Digits shall appear as illuminated characters on a black background, and their dimensions should approximate the following:

a. Height: 1/4-inch (6.4mm).
b. Height-to-Width Ratio: 3:2.
c. Height-to-Stroke Width Ratio: 10:1

5.4.2.2.5.2 External Illumination. - In areas where ambient illumination will provide a display brightness above 1 Ft-L, internal illumination is not required. Digits shall be bold, black numeral engraved on a light (or white) thumbwheel background. The dimensions should approximate those specified in 5.4.3.2.5.1 except that the height-to-stroke-width ratio should be approximately 5:1.

5.4.2.2.6 Visibility. - Thumbwheel design shall permit viewing of inline digital read-out from all operator positions.

5.4.2.2.7 Dimensions. - Control dimensions shall conform to the criteria in Figure 4.

5.4.2.2.8 Resistance

5.4.2.2.8.1 Discrete (Detented) Thumbwheel Controls. - Detents shall be provided for discrete position thumbwheels. Resistance shall be elastic, building up and then decreasing as each detent is approached so that the control snaps into position without stopping between adjacent detents. The resistance shall be within the limits indicated in Figure 4.

5.4.2.2.8.2 Continuous Thumbwheel Controls. - Resistance shall be provided so that definite sustained effort is required for actuation. The resistance incorporated into continuous thumbwheel controls shall be within the following torque limits:

a. Minimum: Determined by jarring, vibration, or other conditions; no practical limit is set by operator performance.

b. Maximum: 6 inch-ounces.

5.4.2.2.9 Separation. - Control separation shall conform to the criteria in Figure 4. The separation between adjacent edges of thumbwheel controls shall, in any case, be sufficient to preclude accidental activation of adjacent controls during normal setting.

5.4.2.3 Continuous Adjustment Rotary Controls

5.4.2.3.1 Knobs

5.4.2.3.1.1 Application. - Knobs should be used when little force is required, and when precise adjustments of a continuous variable are required. A moving knob with fixed scale is preferred over a moving scale with fixed index for most tasks. If positions of non-multirevolution controls must be distinguished, a pointer or marker should be available on the knob.

5.4.2.3.1.2 Dimensions, Torque and Separation. - The dimensions of knobs shall be within the limits specified in Figure 5. Within these ranges, knob size is relatively unimportant, provided the resistance is low and the knob can be easily grasped and manipulated. When panel space is extremely limited, knobs should approximate the minimum values and should have resistance as low as possible without permitting the setting to be changed by merely touching the control. Resistance and separation between adjacent edges of knobs shall conform to Figure 5.

5.4.2.3.2 Cranks. -

5.4.2.3.2.1 Application. - Cranks should be used primarily for tasks requiring many rotations of a control, particularly where high rates or large forces are involved. For tasks involving large slewing movements, plus small, fine adjustments, a crank handle may be mounted on a knob or handwheel -- the crank for slewing and the knob or handwheel for fine adjustments. Where cranks are used for tuning or other processes involving numerical selection, each rotation should correspond to a multiple of 1, 10, 100, etc.

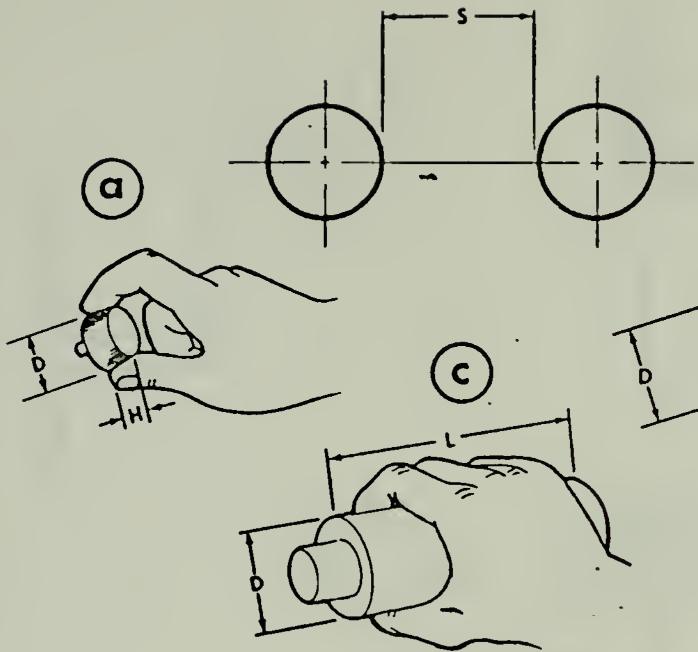
5.4.2.3.2.2 Grip Handle. - The crank grip handle shall be designed so that it turns freely around its shaft.

5.4.2.3.2.3 Dimensions, Resistance and Separation. - Dimensions, resistance and separation between adjacent swept circular areas of cranks shall conform to the criteria of Figure 6.

5.4.2.3.3 Handwheels

5.4.2.3.3.1 Application. - Handwheels, which are designed for two-hand operation, should be used when the breakout or rotational forces are too large to be overcome with a one-hand control, provided that two hands will normally be available for this task.

5.4.2.3.3.2 Knurling. - Knurling or indentation shall be built into a handwheel to facilitate operator grasp.

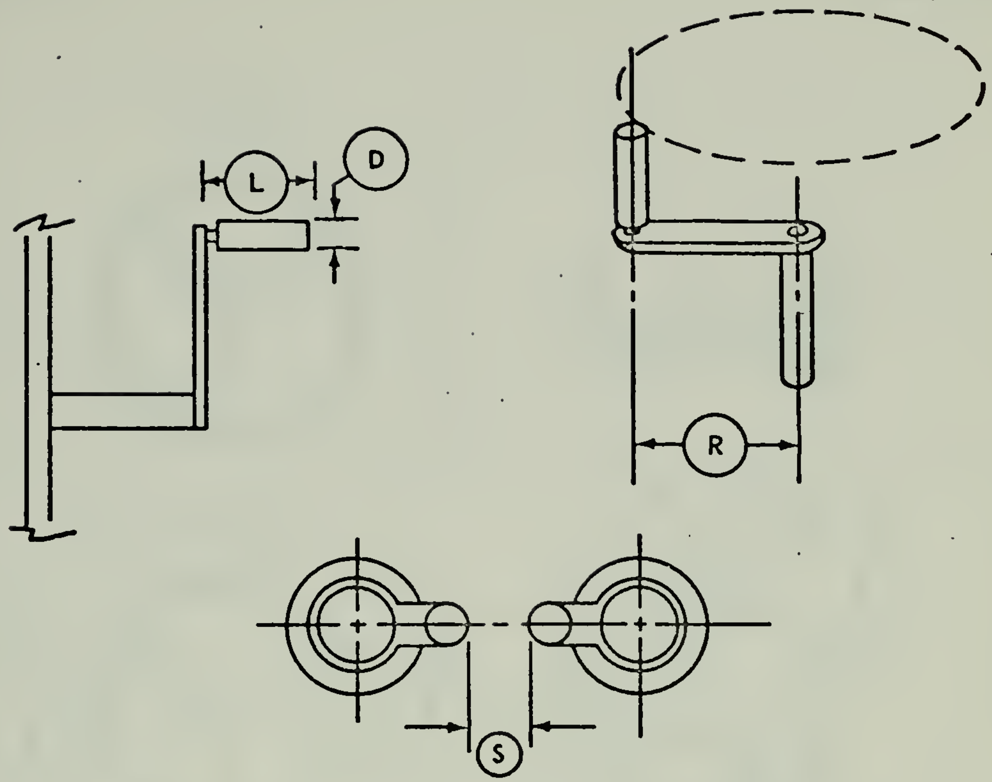


	DIMENSIONS				
	(a) Fingertip Grasp		(b) Thumb and Finger Encircled	(c) Palm Grasp	
	H Height	D Diameter	D Diameter	D Diameter	L Length
Minimum	0.5"	0.375"	1.0"	1.5"	3.0"
Maximum	1.0"	4.0	3.0"	3.0"	-

	TORQUE (in.-oz)		SEPARATION	
	*	**	S One Hand Individually	S Two Hands Simultaneously
Minimum	-		1"	2"
Optimum	-	-	2"	5"
Maximum	4.5	6.0	-	-

* To and including 1.0-in. diameter knobs
** Greater than 1.0-in. diameter knobs

Figure 5. KNOBS

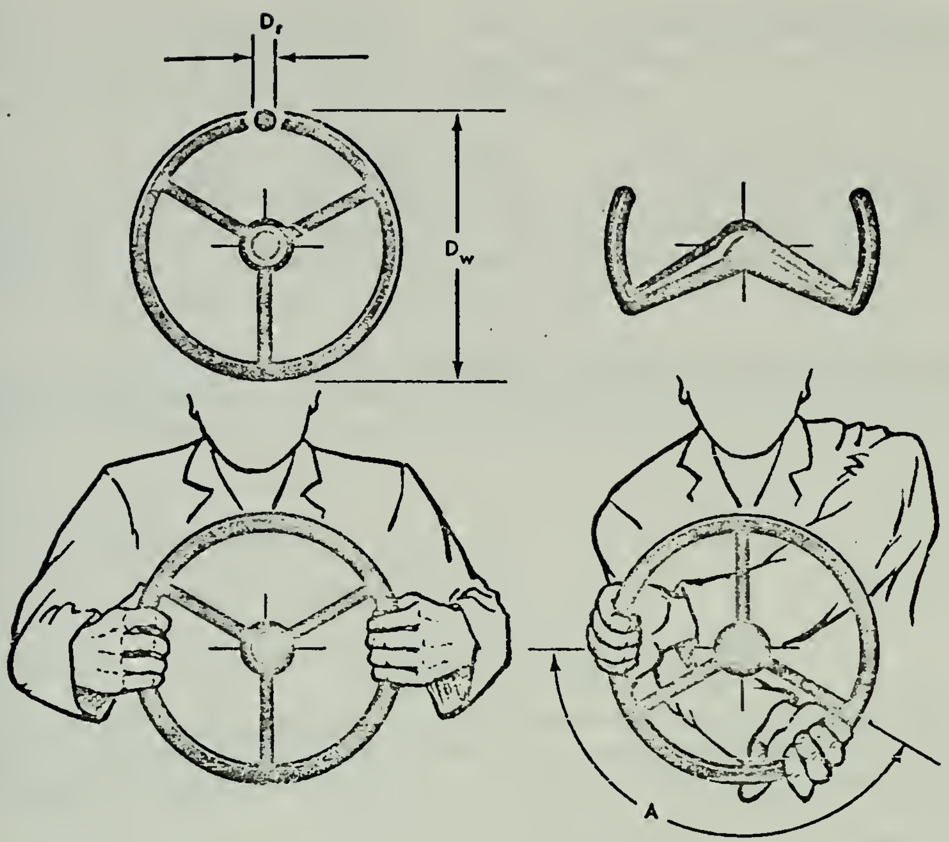


rpm*	DIMENSIONS: Handle D Diameter	DIMENSIONS: Handle L Length	DIMENSIONS: Radius R Minimum	DIMENSIONS: Radius R Maximum
None	1.0"	3.75"	9.0"	16.0"
175	1.0"	3.75"	5.0"	8.0"
275 (max)	0.5"	1.5"	0.5"	4.5"

rpm*	RESISTANCE: Minimum	RESISTANCE: Maximum	SEPARATION S: Minimum	SEPARATION S: Maximum
None	2 lb	50 lb	3"	-
175	6 lb	15 lb	3"	-
275 (max)	2 lb	5 lb	3"	-

* Revolutions per minute required of personnel

Figure 6. CRANKS



	DIMENSIONS			RESISTANCE	
	D_w Wheel Diameter		D_r Rim Diameter		
	One Hand	Two Hands		One Hand	Two Hands
Minimum	2.0"	7.0"	0.75"	5 lb	5 lb
Maximum	4.25"	21.0"	2.0"	30 lb	50 lb

	DISPLACEMENT		SEPARATION
	A		
	One Hand	Two Hands	Two Hands Simultaneously
Minimum	-	-	3"
Maximum	-	120 deg	5"

Figure 7. HANDWHEELS

5.4.2.3.3.3 Spinner Handle. - When large displacements must be rapidly made, a spinner handle may be attached to the handwheel when not precluded by safety considerations.

5.4.2.3.3.4 Direction of Movement. - Except for valves (see 5.4.1.2.4), handwheels shall rotate clockwise for ON or INCREASE and counter-clockwise for OFF and DECREASE. The direction of motion shall be indicated on the handwheel, or immediately adjacent thereto, by means of arrow and appropriate legends.

5.4.2.3.3.5 Dimensions, Resistance, Displacement and Separation. - Control dimensions, resistance, displacement and separation between adjacent edges of handwheels shall conform to the criteria in Figure 7.

5.4.3 Linear Controls

5.4.3.1 Discrete Linear Controls

5.4.3.1.1 Push Buttons (Finger or Hand Operated)

5.4.3.1.1.1 Application. - Push buttons should be used when a control or an array of controls is needed for momentary contact or for activating a locking circuit, particularly in high-frequency-of-use situations.

5.4.3.1.1.2 Shape. - The push button surface should normally be concave (indented) to fit the finger. When this is impractical, the surface shall provide a high degree of frictional resistance to prevent slipping.

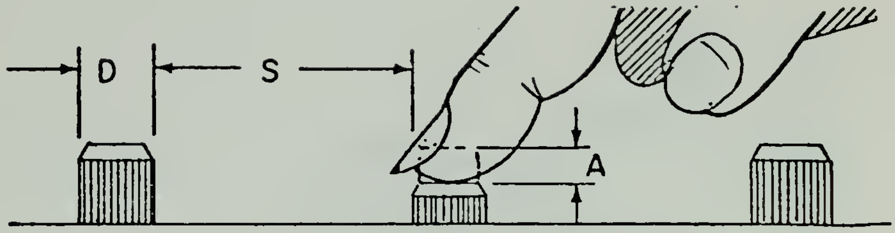
5.4.3.1.1.3 Positive Indication. - A positive indication of control activation shall be provided (e.g., snap feel, audible click, or integral light).

5.4.3.1.1.4 Channel or Cover Guard. - A channel or cover guard shall be provided when it is imperative to prevent accidental activation of the control.

5.4.3.1.1.5 Dimensions, Resistance, Displacement, and Separation. - Except for use of push buttons in keyboards, control dimensions, resistance, displacement, and separation between adjacent edges of finger or hand-operated pushbuttons shall conform to the criteria in Figure 8.

5.4.3.1.1.6 Interlocks or Barriers. - Properly designed mechanical interlocks or barriers may be used instead of the spacing required by Figure 8.

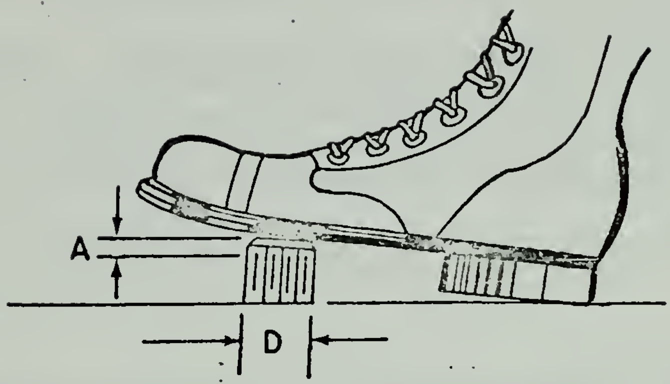
5.4.3.1.2 Push Buttons (Foot-Operated)



	DIMENSIONS		RESISTANCE		DISPLACEMENT
	Diameter D				A
	Fingertip Operation	Thumb or Heel of Hand Operation	Fingertip Operation	Little Finger Operation	Thumb or Finger Operation
Minimum	0.385"	0.75"	10 oz	5 oz	0.125"
Maximum	0.75"	-	40 oz	20 oz	1.5"

	SEPARATION		
	S		
	Single Finger Operation	Single Finger Sequential Operation	Operation by Several Fingers
Minimum	0.5"	0.25"	0.5"
Preferred	2.0"	1.00"	0.5"

Figure 8. PUSHBUTTONS (Finger or Hand Operated)



	DIAMETER	RESISTANCE		DISPLACEMENT			
	D			A			
		Foot Will Not Rest On Control	Foot Will Rest On Control	Normal Operation	Heavy Boot Operation	Ankle Flexion Only	Total Leg Movement
Minimum	0.50"	4.0 lb	10.0 lb	0.50"	1.0"	1.0"	1.0"
Maximum	- -	20.0 lb	20.0 lb	2.5"	2.5"	2.5"	4.0"

Figure 9. PUSHBUTTONS (Foot Operated)

5.4.3.1.2.1 Application. - Foot-operated push buttons should be used only in those cases where the operator is likely to have both hands occupied at the time the push button is activated or when load sharing among limbs is required. Because foot-operated push buttons are extremely susceptible to accidental activation, their uses shall be limited to noncritical operations such as press-to-talk switches.

5.4.3.1.2.2 Operation. - Foot-operated push buttons shall be designed to be operated by the toe and the ball of the foot rather than the heel. Where space permits, foot-operated push buttons shall be replaced by, or supplemented with, a pedal to aid in locating the activating control. Friction surfaces shall be used on foot-operated push buttons.

5.4.3.1.2.3 Positive Indication. - A positive indication of control activation shall be provided (e.g., snap feel, audible click, associated light, or side tone).

5.4.3.1.2.4 Dimensions, Resistance, Displacement, and Separation. - Dimensions, resistance, and displacement of foot-operated push buttons shall conform to the criteria in Figure 9. Separation between adjacent edges of foot-operated pushbuttons shall conform to the criteria in Figure 13.

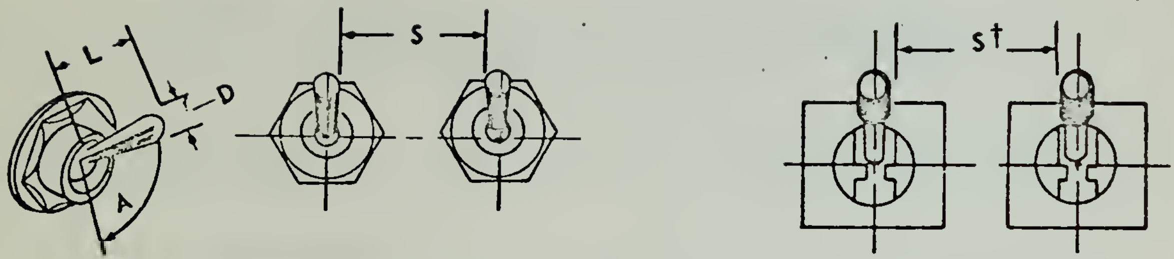
5.4.3.1.3 Toggle Switch Controls

5.4.3.1.3.1 Application. - Toggle switches should be used for functions which require two discrete positions or where space limitations are severe. Toggle switches with three or more positions shall be used only where the use of a rotary control, legend switch control, etc., is not feasible or when the toggle switch is of the spring-loaded, center-position off type. (Toggle switches are considered herein to be discrete position controls. Small controls that are the same size and shape as toggle switches and used for making continuous adjustments are described herein as levers.)

5.4.3.1.3.2 Accidental Activation. - When the prevention of accidental activation is of primary importance (i.e., critical, dangerous, or hazardous conditions would result), channel guards, lift-to-unlock switches, or any other equivalent means will be provided.

5.4.3.1.3.3 Dimensions, Resistance, Displacement, and Separation. - Dimensions, resistance, displacement, and separation between adjacent edges of toggle switches shall conform to the criteria in Figure 10.

5.4.3.1.3.4 Resistance. - Resistance should gradually increase, then drop when the switch snaps into position. The switch shall not be capable of being stopped between positions.



	DIMENSIONS			RESISTANCE		DISPLACEMENT
	L Arm Length *	 **	D Control Tip	Small Switch	Large Switch	A
Minimum	0.5"	1.5"	0.125"	10 oz	10 oz	30 deg
Maximum	2.0"	2.0	1.0"	16 oz	40 oz	120 deg

	SEPARATION S			
	Single Finger Operation	 †	Single Finger Sequential Operation	Simultaneous Operation by Different Fingers
Minimum	0.75"	1.0"	0.5"	0.625"
Optimum	2.0"	2.0"	1.0"	0.75"

*Use by bare finger   **Use by gloved finger   † Using a lever lock toggle switch

Figure 10. TOGGLE SWITCHES

5.4.3.1.3.5 Orientation. - Toggle switches should be vertically oriented with OFF in the down position. Horizontal orientation and actuation of toggle switches shall be employed only for compatibility with the controlled function or equipment location.

5.4.3.1.4 Legend Switches

5.4.3.1.4.1 Dimensions, Resistance, Displacement and Separation. - Dimensions, resistance, displacement, and separation between adjacent edges of legend switches shall conform to the criteria in Figure 11.

5.4.3.1.4.2 Barrier Height. - Barrier height from panel surface shall conform to the criteria in Figure 11.

5.4.3.1.4.3 Other Requirements

a. For positive indication of switch activation, the legend switch shall be provided with a detent or click.

b. The legend shall be legible when only one lamp is operating within the switch.

c. There shall be a press-to-test or dual lamp/filament reliability.

d. Lamps within the legend switch shall be replaceable from the front of the panel by hand and the legends or covers shall be keyed to prevent the possibility of interchanging the legend covers.

e. There shall be a maximum of three lines of lettering on the legend plate.

5.4.3.2 Continuous Adjustment Linear Controls

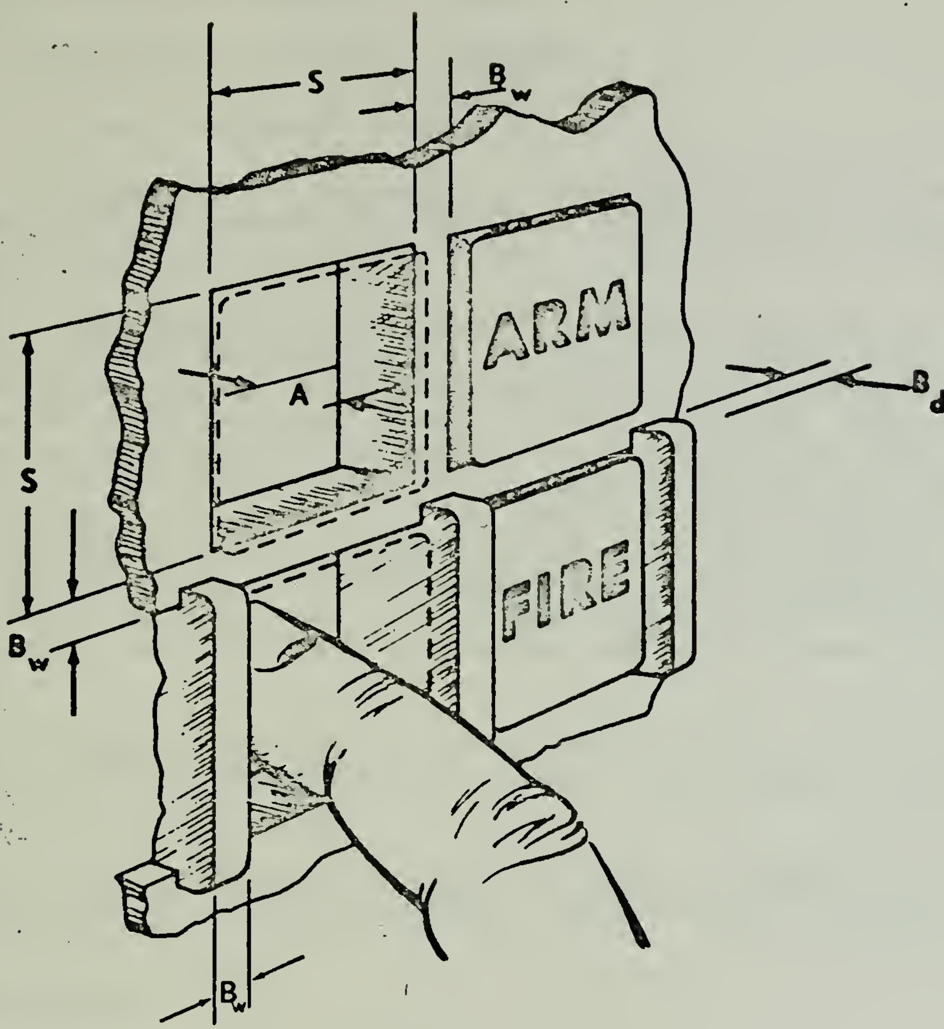
5.4.3.2.1 Levers

5.4.3.2.1.1 Application. - Levers may be used when large amounts of force or displacement are involved or when multidimensional movements of controls are required.

5.4.3.2.1.2 Coding.- When several levers are grouped in proximity to each other, the lever handles shall be coded.

5.4.3.2.1.3 Labeling. - When practicable, all levers shall be labeled as to function and direction of motion.

5.4.3.2.1.4 Limb Support. - When levers will be used to make fine or continuous adjustments, support shall be provided for the appropriate limb segment as follows:



	S Size (in.)	A DISPLACEMENT (in.)	BARRIERS* (in.)		RESISTANCE (oz)
			B_w	B_d	
Minimum	3/4	1/8	1/8	3/16	10
Maximum	1-1/2	1/4	1/4	1/4	45

* Barriers will have rounded edges.

Figure 11. LEGEND SWITCH

a. For large hand movements: elbow

b. For small hand movements: forearm

c. For finger movements: wrist.

5.4.3.2.1.5 Dimensions. - The length of levers shall be determined by the mechanical advantage needed. When the lever or grip handle is spherical, its diameter shall conform with Figure 12.

5.4.3.2.1.6 Resistance. - The resistance incorporated in levers shall be within the limits indicated in Fig. 12 measured as linear force applied to a point on the handle. NOTE: The right hand can apply slightly more force than the left, but the difference is not significant. The same amount of push-pull force can be applied when the control is along the median plane of the body as when it is directly in front of the arm, 7 inches from the median plane. When the control is placed in front of the opposite (unused) arm only 75 percent as much force can be applied. When the control is 10 to 19 inches forward of the seat reference point, twice as much push-pull force can be applied with two hands as with one-hand operation. Outside this range two-hand operation becomes less effective.

5.4.3.2.1.7 Elastic Resistance. - For joystick controls, elastic resistance which increases with displacement may be used to improve "stick feel".

5.4.3.2.1.8 Displacement and Separation. - Control displacement (for the seated operator) and separation shall conform to the criteria in Figure 12.

5.4.3.2.2 Pedals

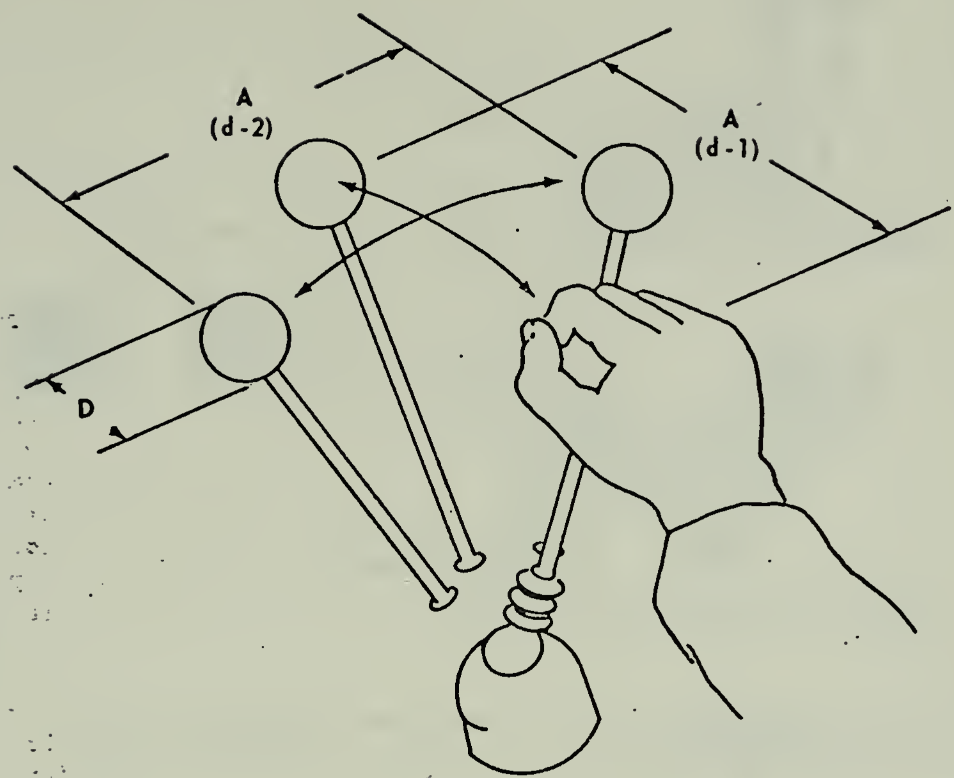
5.4.3.2.2.1 Application. - Pedals shall be used when a large amount of displacement or force is required and when foot activation is desirable.

5.4.3.2.2.2 Null Position. - Pedals should be designed so that they will return to the null position when force is removed.

5.4.3.2.2.3 Dimensions, Resistance, Displacement, and Separation. - Dimensions, resistance, displacement, and separation between adjacent edges of pedals shall conform to the criteria in Figure 13.

5.4.3.2.2.4 Heel Support. - When the pedal angle is greater than 20° above the horizontal, a heel support should be provided.

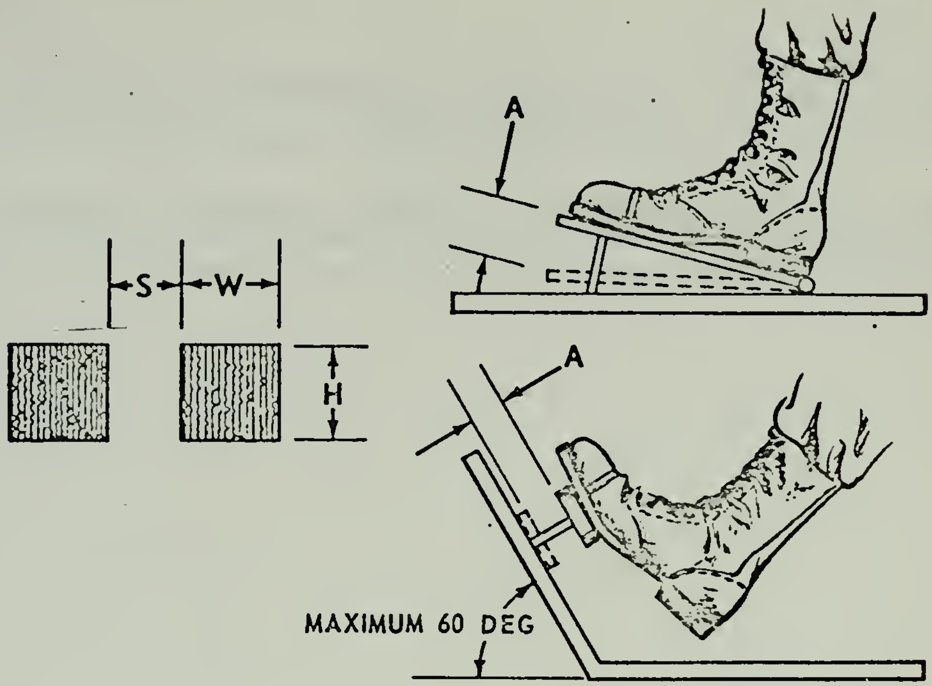
5.4.3.2.2.5 Non-Slip Material. - Pedals shall be covered with a non-slip material.



	DIAMETER D		RESISTANCE (d-1)		RESISTANCE (d-2)	
	Finger Grasp	Hand Grasp	One Hand	Two Hands	One Hand	Two Hands
Minimum	0.5"	1.5"	2 lb	2 lb	2 lb	2 lb
Maximum	3.0"	3.0"	30 lb	50 lb	20 lb	30 lb

	DISPLACEMENT A		SEPARATION	
	Forward (d-1)	Lateral (d-2)	One Hand Random	Two Hands Simultaneously
Minimum	-	-	2"	3"
Preferred			4"	5"
Maximum	14"	38"		

Figure 12. LEVER



	DIMENSIONS		DISPLACEMENT			
	H	W	A			
	Height	Width	Normal Operation	Heavy Boots	Ankle Flexion	Total Leg Movement
Minimum	1.0"	3.0"	0.5"	1.0"	1.0"	1.0"
Maximum	-	-	2.5"	2.5"	2.5"	7.0"

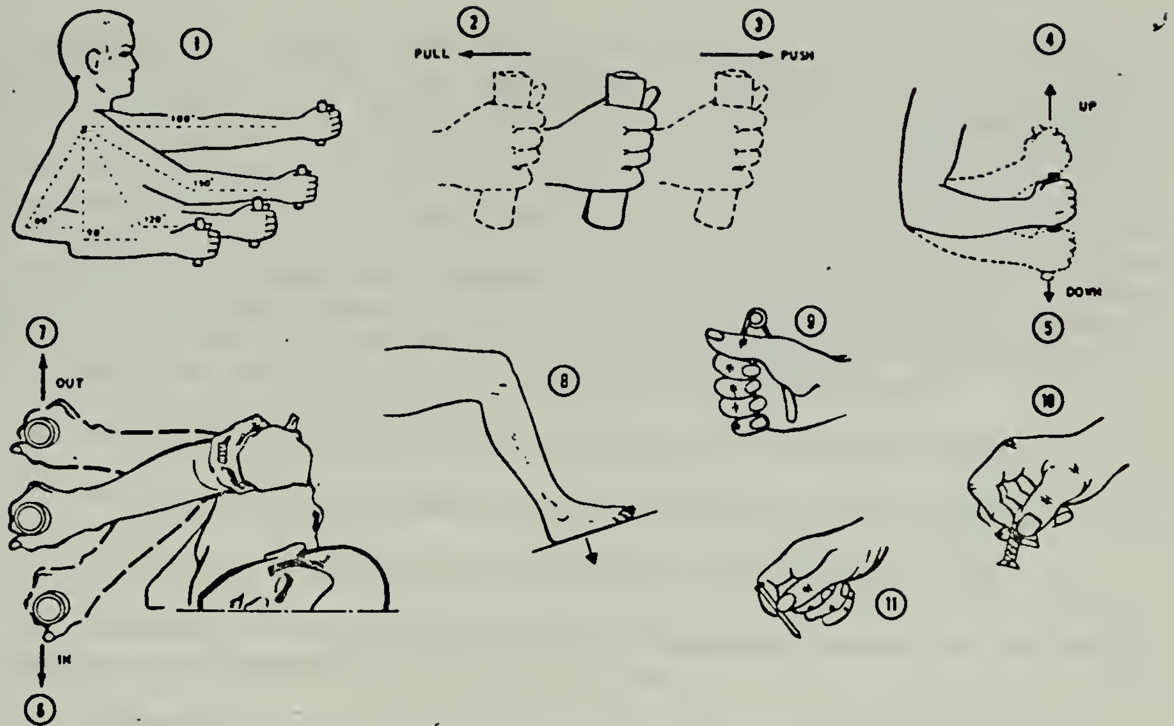
	RESISTANCE			
	Foot Not Resting on Pedal	Foot Resting on Pedal	Ankle Flexion Only	Total Leg Movement
Minimum	4.0 lb	10 lb	-	10 lb
Maximum	20.0 lb	20 lb	10 lb	180 lb

	SEPARATION	
	S	
	One Foot Random	One Foot Sequential
Minimum	4"	2"
Preferred	6"	4"

Figure 13. PEDALS

5.4.3.3 Force-Sensitive Controls. - Force sensitive isometric controls should be considered for use in tracking applications, especially those which must be performed under vibration conditions.

5.4.4 High-Force Controls. - Where controls other than those herein are required and high control forces are used for specific applications, the maximum force requirements shall not exceed those shown by Figure 14.



ARM STRENGTH														
(1)	(2)		(3)		(4)		(5)		(6)		(7)	
Degree of Elbow Flexion	Pull		Push		Up		Down		In		Out	
	R**	L	R	L	R	L	R	L	R	L	R	L
180°	52	50	50	42	14	9	17	13	20	13	14	8
150°	56	42	42	30	18	15	20	18	20	15	15	8
120°	42	34	36	26	24	17	26	21	22	20	15	10
90°	37	32	36	22	20	17	26	21	18	16	16	10
60°	24	26	34	22	20	15	20	18	20	17	17	12

LEG, HAND, AND THUMB FINGER STRENGTH*						
	(8)		(9)		(10)	(11)
	Leg Push		Hand Grip		Thumb-Finger Grip (Palmar)	Thumb-Finger Grip (Tips)
	R	L	R	L		
Momentary Hold	413	387	63	65	15	12
Sustained Hold	200	200	42	38	15	12

* Design values, in pounds, for the given actions

** R = Right L = Left

Figure 14. ARM, HAND, AND FINGER STRENGTH

5.6 ANTHROPOMETRY

5.6.1 General. - Design shall insure operability and maintainability by at least 90 percent of the user population. The design range shall include at least the 5th to 95th percentiles for design-critical body dimensions. (The 5th percentile for a particular dimension is a value such that 5 percent of the personnel are smaller than the value expressed and 95 percent of the personnel are larger; conversely, the 95th percentile for a particular dimension is a value such that 95 percent of the personnel are smaller than the value expressed and 5 percent of the personnel are larger.) The data of this section, shown in Figures 15 through 20 and Table V, provide a basis for design decisions not specifically covered in other sections. Use of these data must take the following into consideration:

a. The nature, frequency, and difficulty of the related tasks

b. The position of the body during performance of these tasks

c. Mobility or flexibility requirements imposed by the tasks

d. Increments in the design-critical dimensions imposed by the need to compensate for obstacles, projections, etc.

e. Increments in the design-critical dimensions imposed by protective garments, packages, lines, padding, etc.

5.6.2 Data Limitations. - The anthropometric data presented in Figures 15 through 20 are nude body measurements, expressed in inches. These data represent U. S. Army Personnel (1966), U. S. Navy Aviators (1964), and U. S. Air Force Officer Flying Personnel (1967). Blanks in the tables indicate that data are not available. Definitive or detailed data should be obtained from the service activity responsible for anthropometry.

5.6.3 Use of Data

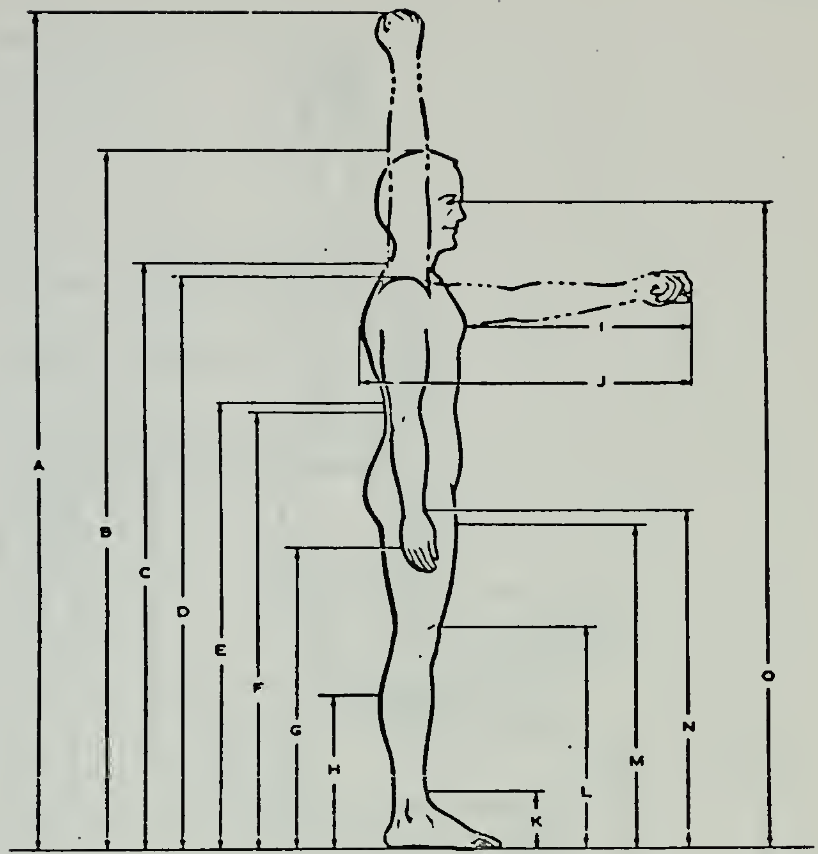
5.6.3.1 Gross Dimensions. - Gross dimensions (passageways, accesses, safety clearances, etc.) which must accommodate or allow passage of the body or parts of the body shall be based upon the 95th percentile values for applicable body dimensions.

5.6.3.2 Limiting Dimensions. - Limiting dimensions (reaching distance, displays, test points, handrails, control movement, etc.) which restrict or are limited by extension of the body shall be based upon the 5th percentile values for applicable body dimensions.

5.6.3.3 Adjustable Dimensions. - Adjustable dimensions (seats, safety goggles, belts, controls, etc.) shall be adjustable to accommodate the range of 5th through 95th percentile values of applicable body dimensions.

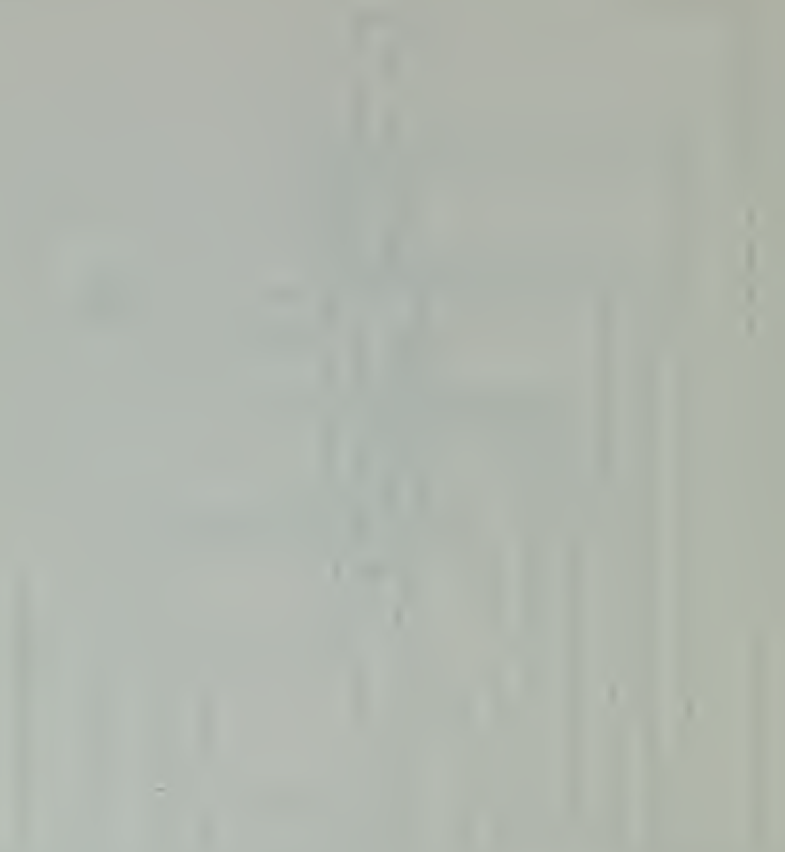
5.6.3.4 <u>Clothing and Personal Equipment</u>. - Clothing and personal equipment worn or carried by the man (including specialized and protective clothing) will be designed and sized to accommodate at least the 5th through 95th percentile values for body size and, where feasible, the 1st through 99th percentile values. Where two or more dimensions are used simultaneously as design parameters, the middle 90 percent of the total user population must be accommodated. To accomplish this, appropriate tables displaying the interrelationships between body size dimensions must be utilized.

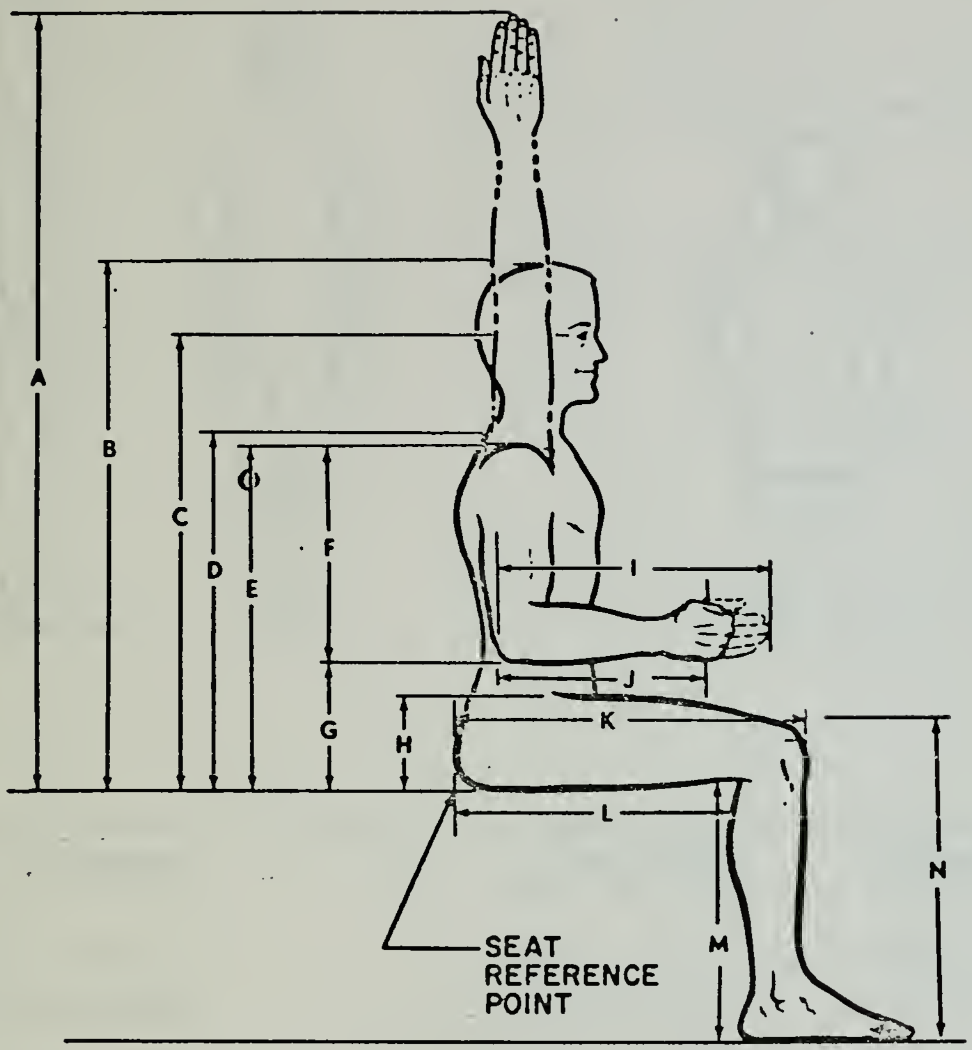
5.6.4 <u>Other Data</u>. - Where equipment will be used, inclusively or exclusively, by specialized populations (e.g., Army aviators, foreign nationals, females, etc.), appropriate available anthropometric data for these specialized populations shall be applied.



	DIMENSIONS	5th PERCENTILE			95th PERCENTILE		
		USA	USN	USAF	USA	USN	USAF
A	Overhead Reach Height			78.6			87.6
B	Stature	64.5	66.2	65.9	73.1	73.9	73.9
C	Cervicale Height	54.8	56.0	56.1	63.0	63.3	63.7
D	Shoulder Height	52.6		53.4	60.7		60.9
E	Elbow Height			41.3			47.3
F	Waist Height	38.4	39.4	38.9	45.3	45.3	45.0
G	Knuckle Height			27.7			32.4
H	Calf Height	12.2		12.6	15.7		15.5
I	Depth of Reach						
	One Arm			20.2			26.8
	Both Arms			19.2			24.5
J	Functional Reach	29.5	29.3	29.1	35.8	34.0	34.3
K	Ankle Height			4.7			6.2
L	Kneecap Height (top)	18.8	19.3	19.1	23.0	22.8	22.4
M	Crotch Height	29.6	30.6	30.8	35.7	36.0	36.2
N	Wrist Height			31.6			36.7
O	Eye Height			61.2			69.1

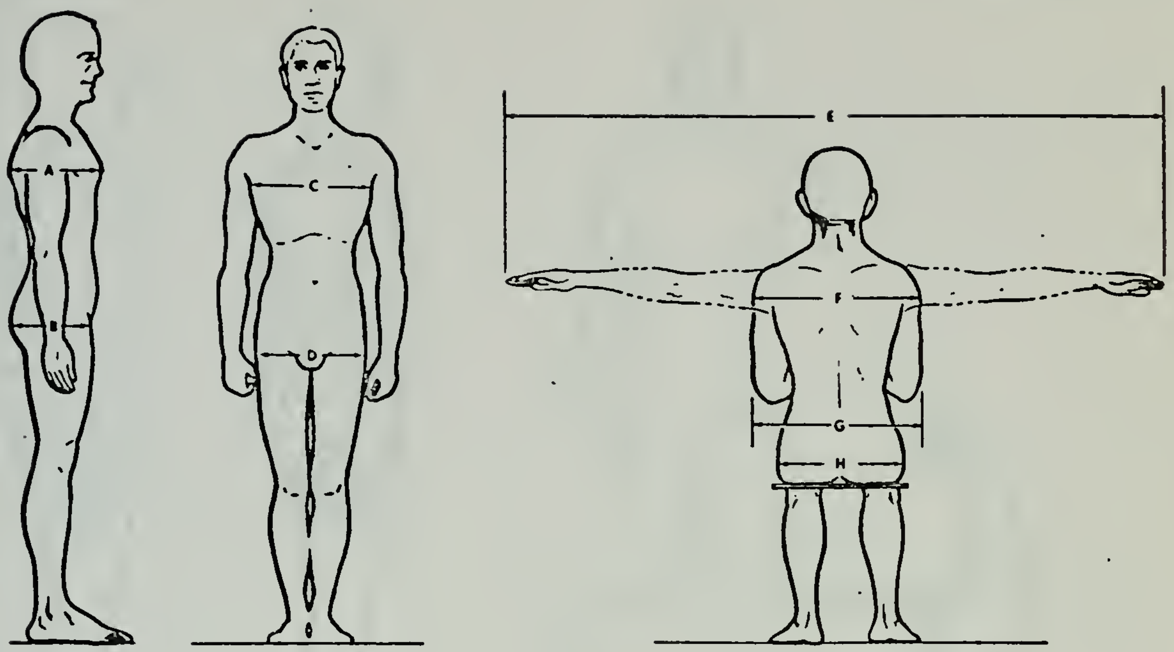
Figure 15. STANDING BODY DIMENSIONS, IN INCHES





	DIMENSIONS	5th PERCENTILE USA	5th PERCENTILE USN	5th PERCENTILE USAF	95th PERCENTILE USA	95th PERCENTILE USN	95th PERCENTILE USAF
A	Vertical Reach	50.7			58.2		
B	Sitting Height	33.3	34.2	34.7	38.1	38.4	38.8
C	Eye Height, Sitting	28.6	29.7	30.0	33.3	33.6	33.9
D	Mid-Shoulder Height	22.5		23.7	26.6		27.3
E	Shoulder Height		22.0	22.2		25.5	25.9
F	Shoulder-Elbow Length	13.3	13.4	13.1	15.7	15.6	15.3.
G	Elbow Rest Height		7.6	8.2		10.9	11.6
H	Thigh Clearance Height			5.6			7.4
I	Elbow-Fingertip Length	17.4	17.9		20.4	20.4	
J	Elbow-Grip Length			12.8			14.9
K	Buttock-Knee Length	21.6	22.5	22.1	25.3	25.8	25.6
L	Buttock-Popliteal Length	17.6	18.2	18.2	20.9	21.4	21.5
M	Popliteal Height	15.6	15.9	15.8	18.8	18.8	18.7
N	Knee Height	19.6	20.3	20.4	23.1	23.5	23.6

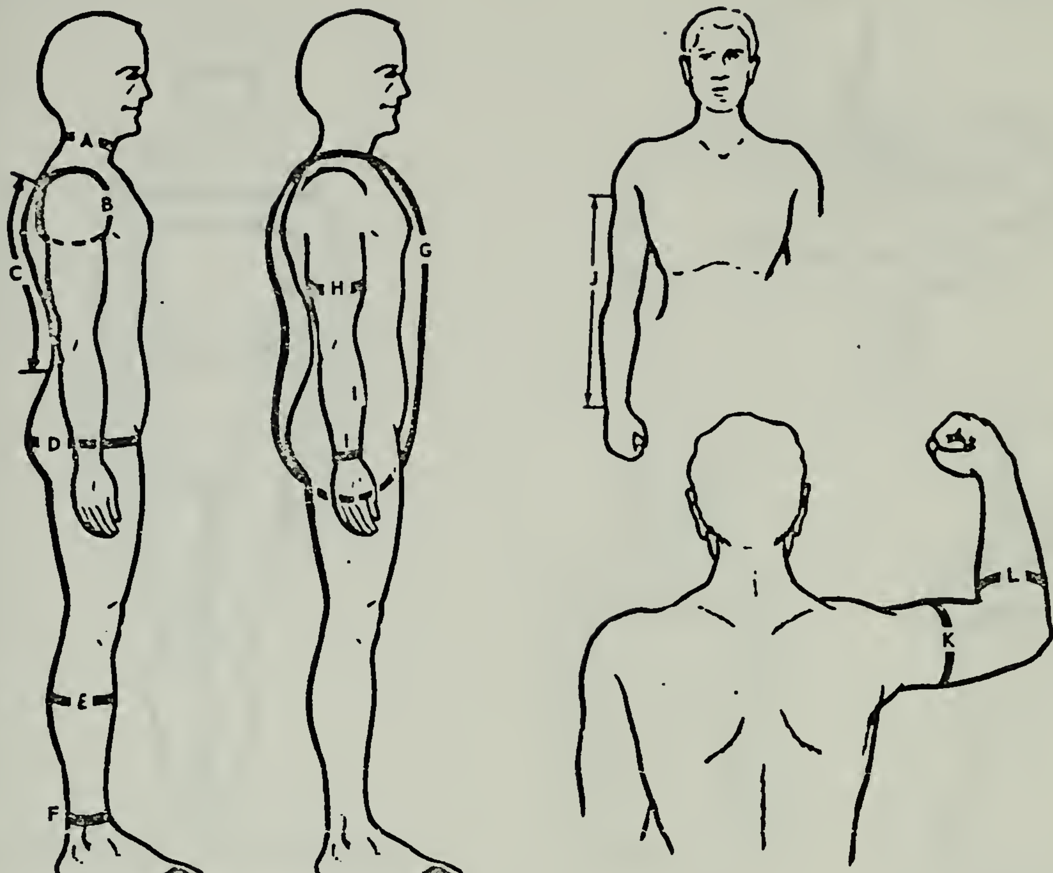
Figure 16. SEATED BODY DIMENSIONS, IN INCHES



	DIMENSIONS	5th PERCENTILE			95th PERCENTILE		
		USA	USN	USAF	USA	USN	USAF
A	Chest Depth	8.0	8.2	8.4	10.5	10.6	10.9
B	Buttock Depth		8.3	8.2		10.7	10.8
C	Chest Breadth	10.8	11.6	11.6	13.5	14.3	14.4
D	Hip Breadth, Standing	11.9	12.6	12.7	14.4	14.9	15.2
E	Span			65.9			75.6
F	Shoulder Breadth	16.3	17.3	17.4	19.6	20.3	20.7
G	Forearm-Forearm Breadth*	15.7		19.0	21.1		23.9
H	Hip Breadth, Sitting	12.1	13.1	13.5	15.1	15.9	16.4

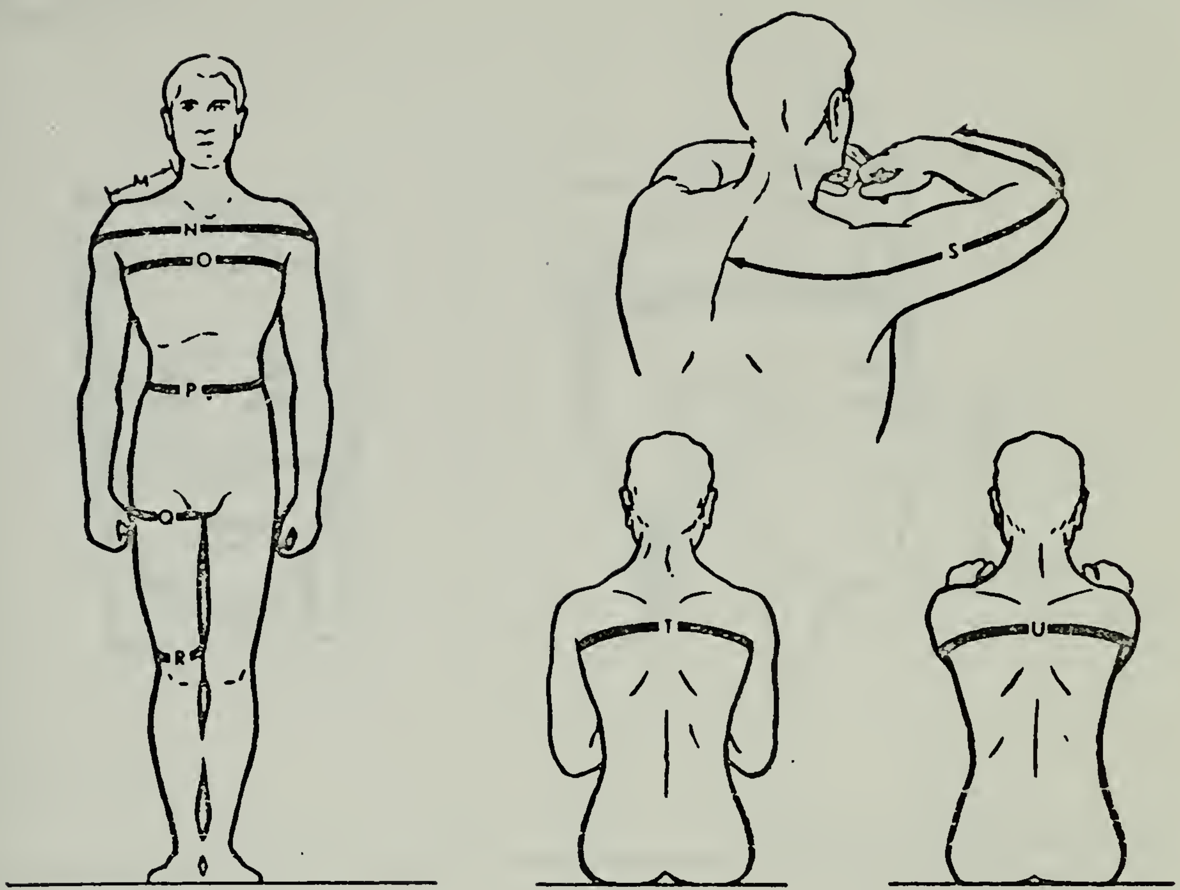
*USA and USAF dimensions not comparable

Figure 17. BREADTH AND DEPTH DIMENSIONS, IN INCHES



	DIMENSIONS	5th PERCENTILE USA	USN	USAF	95th PERCENTILE USA	USN	USAF
A	Neck Circumference	13.5	14.0	13.9	16.1	16.4	16.4
B	Arm Scye Circumference	15.6	16.1	17.2	19.8	19.5	20.9
C	Waist Back Length	15.6		17.0	20.0		20.1
D	Hip Circumference	33.5	35.2	35.3	41.6	41.8	42.5
E	Calf Circumference	12.8	13.4	13.2	16.2	16.3	16.1
F	Ankle Circumference	8.1	8.1	8.0	9.9	9.7	9.7
G	Vertical Trunk Circumference	59.3	61.6	61.7	70.3	70.2	71.0
H	Biceps Circumference, Relaxed	10.0		10.6	13.5		13.7
I	Wrist Circumference	6.2	6.2	6.4	7.3	7.2	7.6
J	Sleeve Inseam Length	17.4	16.8	17.5	20.9	19.9	20.8
K	Biceps Circumference, Flexed	11.0	11.4	11.5	14.6	14.5	14.4
L	Forearm Circumference, Flexed	10.3	10.7	10.7	13.0	13.0	12.8

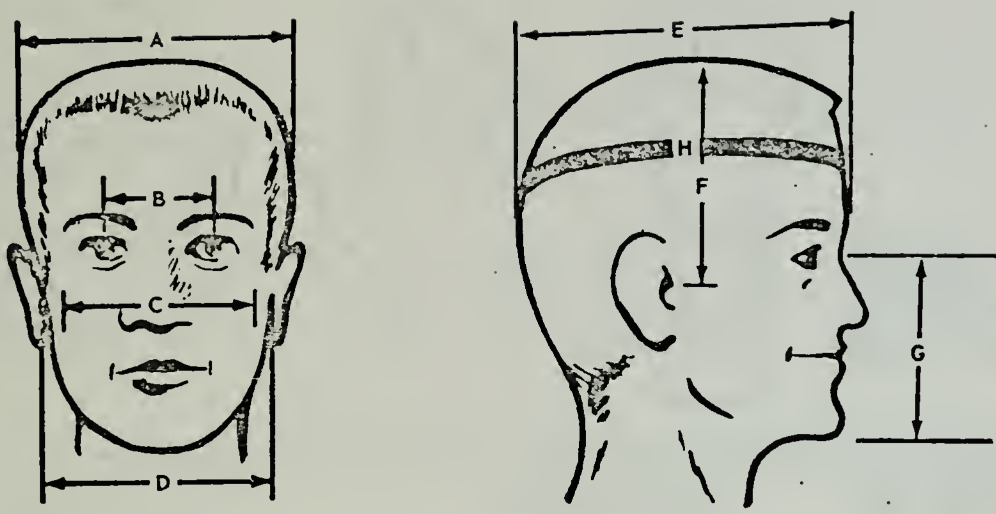
Figure 18. CIRCUMFERENCES AND SURFACE DIMENSIONS, IN INCHES (Continued)



	DIMENSIONS	5th PERCENTILE USA	USN	USAF	95th PERCENTILE USA	USN	USAF
M	Shoulder Length	5.0		5.8	7.6		7.4
N	Shoulder Circumference	40.7	42.3	42.7	48.9	49.4	50.3
O	Chest Circumference	33.1	35.2	34.9	41.7	42.7	43.1
P	Waist Circumference	27.4	29.3	29.8	37.8	37.8	39.4
Q	Upper Thigh Circumference	18.9	20.0	20.3	25.1	25.2	26.0
R	Lower Thigh Circumference	13.6	14.1	15.1	18.6	18.0	19.6
S	Sleeve Length	31.3	32.8	33.5	36.4	37.4	38.1
T	Interscye Breadth	13.4	14.2	12.8	17.4	18.2	17.7
U	Interscye Maximum*	18.3	19.1	22.3	23.1	23.6	26.2

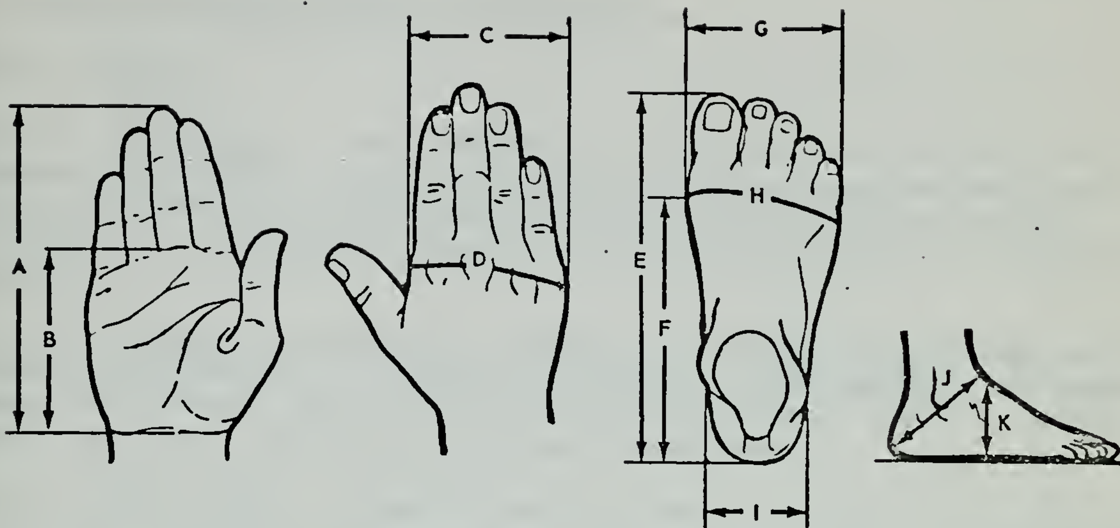
*USAF dimensions not comparable with USA and USN dimensions

Figure 18 (Concluded). CIRCUMFERENCES AND SURFACE DIMENSIONS, IN INCHES



	DIMENSIONS	5th PERCENTILE			95th PERCENTILE		
		USA	USN	USAF	USA	USN	USAF
A	Head Breadth	5.65	5.69	5.80	6.40	6.47	6.50
B	Interpupillary Breadth	2.15	2.39	2.24	2.67	2.75	2.71
C	Face Breadth	5.15	4.87	5.27	5.88	5.79	5.94
D	Bitragion Breadth	4.95	5.17	5.26	5.69	5.85	5.98
E	Head Length	7.19	7.38	7.39	8.14	8.24	8.27
F	Head Height	4.69	4.74	4.89	5.72	5.57	5.69
G	Face Length	4.31	4.23	4.35	5.17	5.48	5.13
H	Head Circumference	21.07	21.74	21.74	23.16	23.57	23.59

Figure 19. HEAD AND FACE DIMENSIONS, IN INCHES

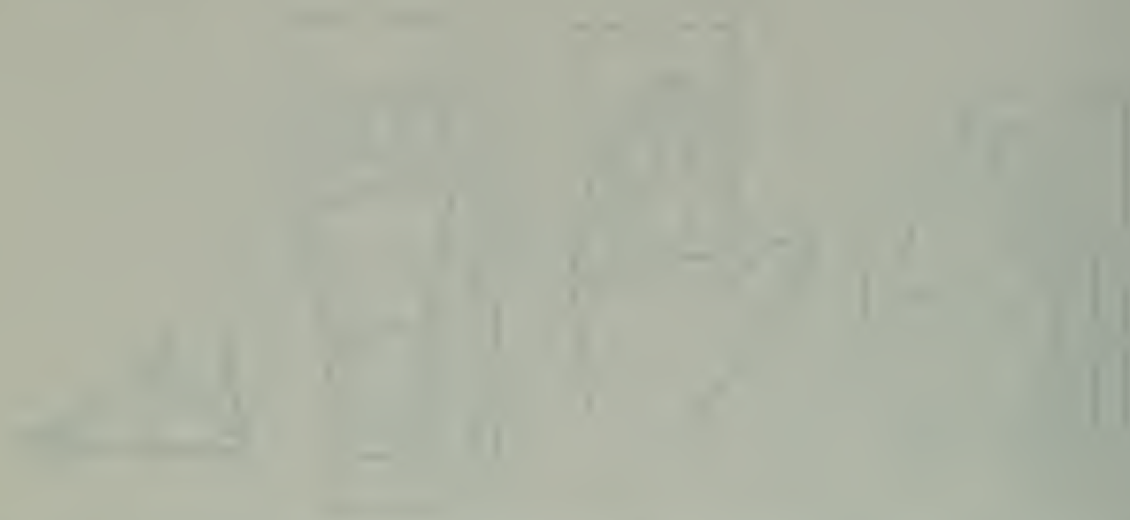


	HAND DIMENSIONS	5th PERCENTILE USA	5th PERCENTILE USN	5th PERCENTILE USAF	95th PERCENTILE USA	95th PERCENTILE USN	95th PERCENTILE USAF
A	Hand Length	6.90	6.98	7.00	8.13	8.09	8.07
B	Palm Length	3.77		3.92	4.59		4.63
C	Hand Breadth	3.20	3.25	3.24	3.83	3.80	3.78
D	Hand Circumference	7.81	7.76	7.89	9.28	9.06	9.11
	FOOT DIMENSIONS						
E	Foot Length	9.71	9.73	9.89	11.41	11.29	11.44
F	Instep Length	7.06		7.18	8.41		8.42
G	Ball of Foot Breadth	3.53	3.58	3.54	4.24	4.58	4.18
H	Ball of Foot Circumference	8.86		9.02	10.78		10.62
I	Heel Breadth	2.42		2.40	3.02		2.87
J	Heel-Ankle Circumference	12.38		12.47	14.53		14.30
K	Instep Circumference	9.43		9.38	11.56		10.95

Figure 20. HAND AND FOOT DIMENSIONS, IN INCHES

TABLE V. AGE AND WEIGHT

AGE/WEIGHT	5th PERCENTILE USA	5th PERCENTILE USN	5th PERCENTILE USAF	95th PERCENTILE USA	95th PERCENTILE USN	95th PERCENTILE USAF
Age (years)	18.6		22.4	31.5		42.4
Weight (pounds)	126.3	140.3	140.0	201.9	203.6	211.0



5.7 GROUND WORKSPACE DESIGN REQUIREMENTS

5.7.1 General

5.7.1.1 Kick Space. - All cabinets, consoles, and work surfaces that require an operator to stand or sit close to their front surfaces shall contain a kick space at the base at least 4 inches (10.2 cm) deep and 4 inches (10.2 cm) high, or greater to allow for protective or specialized apparel.

5.7.1.2 Handles. - Handles on cabinets and consoles shall be recessed whenever practicable, to eliminate projections on the surface. If handles cannot be recessed, they shall be designed such that they shall neither injure personnel nor entangle clothing or equipment.

5.7.1.3 Work Space. - Whenever feasible, free floor space of at least 4 feet (122 cm) shall be provided in front of each console. For equipment racks that require maintenance, free floor space shall be provided in accordance with the following criteria, whenever feasible:

5.7.1.3.1 Depth of Work Area. - The distance from the front of the rack to the opposite surface or obstacle shall be no less than 42 inches (107 cm).

5.7.1.3.2 Lateral Work Space. - The minimum lateral workspace for racks having drawers shall be as follows (measured from drawers in the extended position):

a. For racks having drawers weighing less than 45 pounds (20.4 kg): 18 inches (46 cm) on one side and 4 inches (10.2 cm) on the other.

b. For racks having drawers weighing over 45 pounds (20.4 kg): 18 inches (46 cm) on each side.

5.7.1.3.3 Storage Space. - Adequate and suitable space shall be provided on consoles for the storage of manuals, worksheets, and other materials that will be used by the operational or maintenance personnel.

5.7.1.4 Panel Slope. - For normal console operation, the slope of the control-display panel surface shall begin at the level of the console shelf.

5.7.2 Standing Operations

5.7.2.1 Work Surface. - Convenient work surfaces to support job instruction manuals, worksheets, etc., shall be provided for standing operators. Work benches and other work surfaces shall be 36 inches (91 cm) above the floor, unless otherwise specified.

5.7.2.2 Display Placement, Normal. - Visual displays mounted on vertical panels and used in normal equipment operation shall be placed in an area between 41 inches (104 cm) and 74 inches (188 cm) above the standing surface.

5.7.2.3 Display Placement, Special. - Indicators that must be read precisely and frequently shall be placed in an area between 50 inches (127 cm) and 69 inches (175 cm) above the standing surface.

5.7.2.4 Control Placement, Normal. - All controls mounted on a vertical surface and used in normal equipment operation shall be located in an area between 34 and 74 inches (86 and 188 cm) above the standing surface.

5.7.2.5 Control Placement, Special. - Controls requiring precise or frequent operation and emergency controls shall be mounted between 34 and 57 inches (86 and 145 cm) above the standing surface and no further than 22 inches (56 cm) laterally from the centerline.

5.7.3 Seated Operations

5.7.3.1 Work Surface Width. - A lateral workspace of at least 30 inches (76 cm) wide and 16 inches (41 cm) deep shall be provided whenever practicable.

5.7.3.2 Work Surface Height. - Desk tops and writing tables shall be 30 inches (76 cm) above the floor, unless otherwise specified.

5.7.3.3 Writing Surfaces. - Where a writing surface is required on equipment consoles, it shall be at least 16 inches (41 cm) deep and should be at least 23 inches (61 cm) wide.

5.7.3.4 Seating

5.7.3.4.1 Compatibility. - Work seating shall provide an adequate supporting framework for the body relative to the activities that must be carried out. Chairs to be used with "sit" consoles shall be designed to be operationally compatible with the console configuration.

5.7.3.4.2 Vertical Adjustment. - Provision shall be made for vertical seat adjustment from 16 to 21 inches (41 to 53 cm) in increments of no more than 1 inch (25mm) each.

5.7.3.4.3 Backrest. - A supporting backrest that reclines between 103° and 115° shall be provided. The backrest shall engage the lumbar and thoracic regions of the back, and shall support the torso in such a position that the operator's eyes can be brought to the "Eye Line" with no more than 3 inches (76mm) of forward body movement.

5.7.3.4.4 Cushioning. - Where applicable, both the backrest and seat shall be cushioned with at least 1 inch (25mm) of compressible material and provided with a smooth surface.

5.7.3.4.5 Armrests. - Unless otherwise specified, armrests shall be provided. Armrests that are integral with operators' chairs shall be at least 2 inches (5cm) wide and 8 inches (20 cm) long. Modified or retractable armrests shall be provided when necessary to maintain compatibility with an associated console and shall be adjustable from 7.5 to 11 inches (19 to 28 cm) above the compressed sitting surface.

5.7.3.5 Knee Room. - Knee and foot room that equals or exceeds the following minimum dimensions shall be provided beneath work surfaces:

a. Height: 25 inches (64 cm). If a footrest is provided, this dimension shall be increased accordingly.

b. Width: 20 inches (51 cm).

c. Depth: 18 inches (46 cm).

5.7.3.6 Display Placement, Normal. - Visual displays mounted on vertical panels and used in normal equipment operation shall be placed in an area between 6 and 48 inches (15 and 122 cm) above the sitting surface.

5.7.3.7 Display Placement, Special. - Indicators that must be read precisely and frequently shall be placed in an area between 14 and 37 inches (36 and 95 cm) above the sitting surface, and no further than 22 inches (56 cm) laterally from the centerline.

5.6.3.8 Warning Displays. - For "sit" consoles requiring horizontal vision over the top, critical visual warning displays shall be mounted at least 22.5 inches (57 cm) above the sitting surface.

5.7.3.9 Control Placement, Normal. - All controls mounted on a vertical surface and used in normal equipment operation shall be located in an area between 8 and 35 inches (20 and 90 cm) above the sitting surface.

5.7.3.10 Control Placement, Special. - Controls requiring precise or frequent operation shall be mounted between 8 and 30 inches (20 and 76 cm) above the sitting surface.

5.7.4 Unusual Positions. - The design for workspaces with shirt-sleeve environment for work to be accomplished in the squatting, stooping, kneeling, crawling or prone positions, shall conform to the "preferred" dimensions shown in Table VI and illustrated in Figure 21. These unusual workspaces shall conform to the "Arctic" dimensions shown in Table VI whenever bulky outer clothing is required for environmental protection. In no case shall clearance dimensions be less than the minimum values specified.

5.7.5 Standard Console Design

TABLE VI. CLEARANCE DIMENSIONS

KEY TO FIG. 21	DIMENSION	MINIMUM in. (cm)	PREFERRED* in. (cm)	ARCTIC in. (cm)
	Squatting workspace:			
A	Height:	48 (122)	--	51 (130)
B	Depth:	27 (69)	36 (91)	40 (102)
	Display area:	--	27-43 (69-109)	--
	Control area:	--	19-34 (48-86)	--
	Stooping workspace:			
C	Depth:	36 (91)	40 (102)	44 (112)
	Display area:	--	32-48 (81-122)	--
	Control area:	--	24-39 (61-99)	--
	Kneeling workspace:			
D	Depth:	42 (107)	48 (122)	50 (127)
E	Height:	56 (142)	--	59 (150)
F	Optimum work point:		27 (69)	
	Display area:	--	28-44 (71-112)	--
	Control area:	--	20-35 (51-89)	
	Kneeling crawlspace:			
G	Height:	31 (79)	36 (91)	38 (97)
H	Length:	59 (150)	--	62 (157)
	Prone work or crawlspace:			
I	Height:	17 (43)	20 (51)	24 (61)
J	Length:	96 (244)	--	--
	Supine workspace:			
K	Height:	20 (51)	24 (61)	26 (66)
L	Length:	74 (188)	76 (193)	78 (198)

* The values for display and control areas represent vertical measurements from the floor.

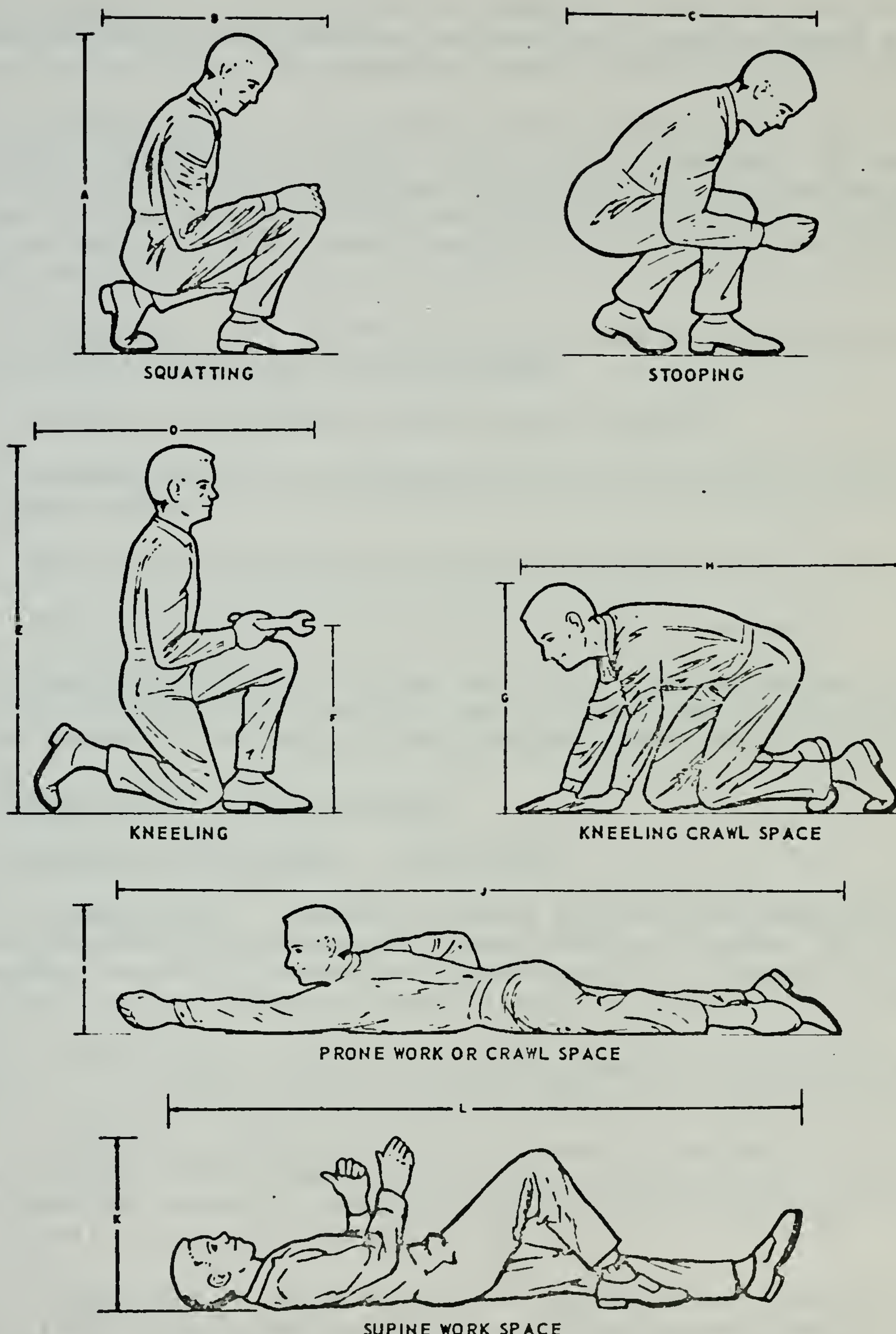


Figure 21. CLEARANCE DIMENSIONS

5.7.5.1 Dimensions. - For purposes of standardization, consoles and the units and racks which constitute operator work stations should be designed to conform with the dimensions shown in Table VII and Figure 22.

5.7.5.2 Configurations. - The configurations represented in Table VII and Figure 22 may not be applicable to all design situations. In some cases, however, operational requirements may necessitate unique design solutions. Because of the benefits and economies inherent in a standard console and unit, the design shall conform with the standard configurations whenever feasible.

5.7.5.3 Variables. - The following variables should be considered in choosing the most appropriate console design:

a. visibility requirement over the top of console.

b. Operator mobility requirement (e.g., "sit", "stand", or "sit-stand" requirements).

c. Panel space required. (Note columns "C" and "N", Table VII

d. Volume required in the area below the writing surface.

5.7.5.4 Console Selection. - On the basis of the considerations in 5.7.5.3, the particular configuration that will best meet the requirements should be selected from among the nine consoles represented in Table VII

5.7.6 Special-Purpose Console Design

5.7.6.1 Horizontal Wrap-Around (Figure 23)

5.7.6.1.1 Panel Width. - When requirements for preferred panel space for a single seated operator exceed a panel width of 44 inches (112 cm), a flat-surface, segmented, wrap-around console should be provided, so as to place all controls within the reach of the 5th percentile stationary operator.

5.7.6.1.2 Panel Angle. - The left and right segments should be placed at an angle , measured from the frontal plane of the central segment, such that they can be reached by the 5th percentile stationary operator.

5.7.6.1.3 Dimensions (Vision Over Top). - Where vision over the top is required (thereby limiting vertical panel space), the width of the central segment shall not exceed 44 inches (112 cm), and that of the left and right segments shall not exceed 24 inches (61 cm).

5.7.6.1.4 Dimensions. - Where vision over the top is not required, i.e., the total console height may exceed the seat height by more than 29.5 inches (75 cm), the width of the central segment shall not exceed 34 inches (86 cm), and that of the left and right segments should not exceed 24 inches (61 cm).

5.7.6.1.5 Viewing Angle. - The total required left-to-right viewing angle shall not exceed 190° (see Fig. 2). This angle should be reduced whenever possible through appropriate control-display layout.

5.7.6.2 Vertical/Stacked Segments (See Figure 24 for example.)

5.7.6.2.1 Panel Division. - Where direct forward vision over the top of the console is not required by a seated operator, and when lateral space is limited, the panel shall be divided into three vertical/stacked segments whose surfaces should be perpendicular to the operator's line of sight with little or no head movement.

5.7.6.2.2 Height. - The center of the central segment should be 31.5 inches (80 cm) above the seat reference point. The height of this segment shall not exceed 21 inches (53 cm).

5.7.6.3 Sit-Stand Consoles. - Where personnel will work from standing or seated positions, console dimensions should conform to those of Table VII.

5.7.7 Stairs, Stair-Ladders, Fixed Ladders, and Ramps

5.7.7.1 General Criteria

5.7.7.1.1 Selection. - The selection of stairs, stair-ladders, fixed ladders, or ramps for specific applications shall be based on the angle of ascent required and the criteria in Figure 25.

5.7.7.1.2 Provision for Hand-Carrying Equipment. - Ramps, elevators, or equivalent means should be provided when equipment must be hand carried. Ladders shall not be selected in such cases, since both hands should be free to grasp the ladder. Stairs and steps should not be used where hand-carrying bulky loads or loads in excess of 40 pounds (18kg) is required.

5.7.7.1.3 Handrails and Guardrails. - Stairs, stair-ladders, fixed ladders, and ramps should be equipped with a handrail on each side. Where one or both sides are open, appropriate intermediate guardrails shall be provided to prevent personnel injury.

5.7.7.2 Stairs. - Stairs should be designed to conform with the recommended dimensions in Figure 26. In no instance shall the dimensions exceed the specified minima or maxima.

5.7.7.3 Stair Ladders. - Stair ladders should be designed to conform with the recommended dimensions in Figure 27. In no instance shall the given dimensions exceed the specified minima or maxima. The tread rise shall be open at the rear. Landings should be provided every tenth or twelfth tread. The surface of treads on exterior stair ladders should be constructed of open grating material or should be treated with nonskid

TABLE VII. STANDARD CONSOLE DIMENSIONS

TYPE OF CONSOLE	Maximum Total Console Height from Standing Surface	Console Depth at Base	Suggested Vertical Dimension of Console Panel (including sills)	Console Panel Angle (from vertical)	Minimum Shelf Depth	Eye-Line-to-Panel-Base Distance	Writing Surface Depth including Shelf	Minimum Knee Clearance	Foot Support to Sitting Surface[1]	Seat Adjustability	Minimum Thigh Clearance at Mid-Point of "J"	Writing-Surface-Shelf Height from Standing Surface	Seat Height from Standing Surface at Mid-Point of "J"	Maximum Console Width (not shown)
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1. Sit (w/vision over top)*	47.5"	Opt	22"	15°	4"	16"	16"	18"	18"	5"	6.5"	25.5"	18"	44"
	54	Opt	22	15	4	16	16	18	18	5	6.5	32	23	44
	58	Opt	22	15	4	16	16	18	18	5	6.5	36	28.5	44
2. Sit (w/o vision over top)*	51.5	Opt	26	15	4	16	16	18	18	5	6.5	25.5	18	36
	58	Opt	26	15	4	16	16	18	18	5	6.5	32	23	36
	62	Opt	26	15	4	16	16	18	18	5	6.5	36	28.5	36
3. Sit-Stand (w/standing vision over top)	62	Opt	26	15	4	16	16	18	18	5	6.5	36	28.5	36
4. Stand (w/vision over top)	62	Opt	26	15	4	16	16	NA	NA	NA	NA	36	NA	44
5. Stand (w/o vision over top)	72	Opt	36	15	4	16	16	NA	NA	NA	NA	36	NA	36

* The range in "A" is provided to allow latitude in the volume of the lower part of the console; note relationship to "L" and "M".

[1] Since this dimension must not be exceeded, a heel catch must be added to the chair if "M" exceeds 18".

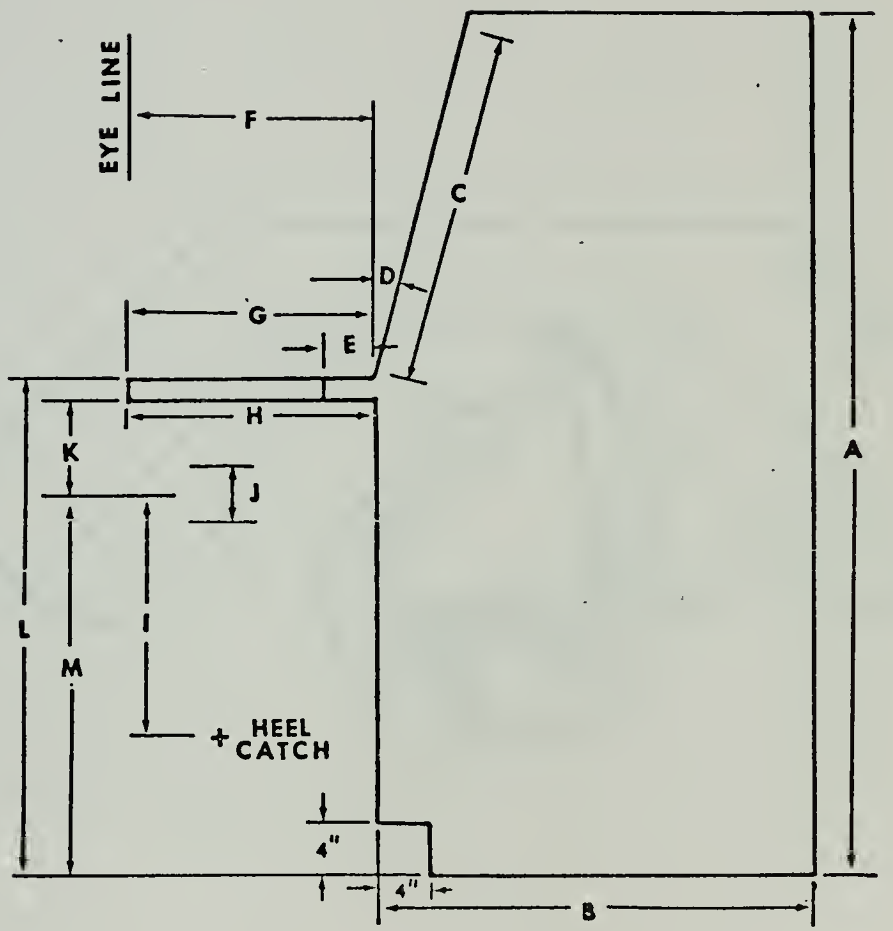


Figure 22. STANDARD CONSOLE DIMENSIONS KEY

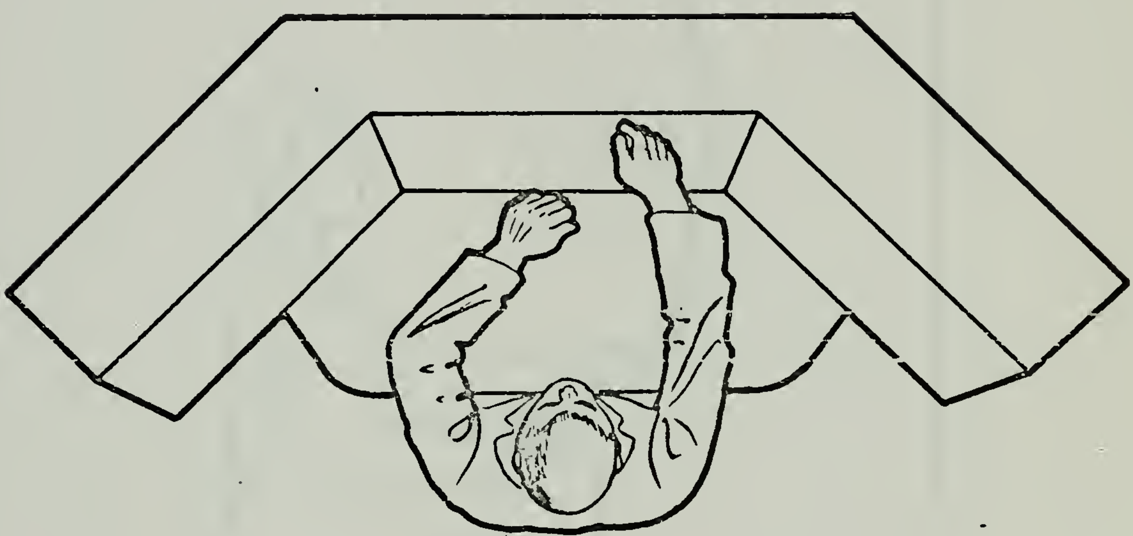


Figure 23. EXAMPLE OF HORIZONTAL WRAP-AROUND CONSOLE

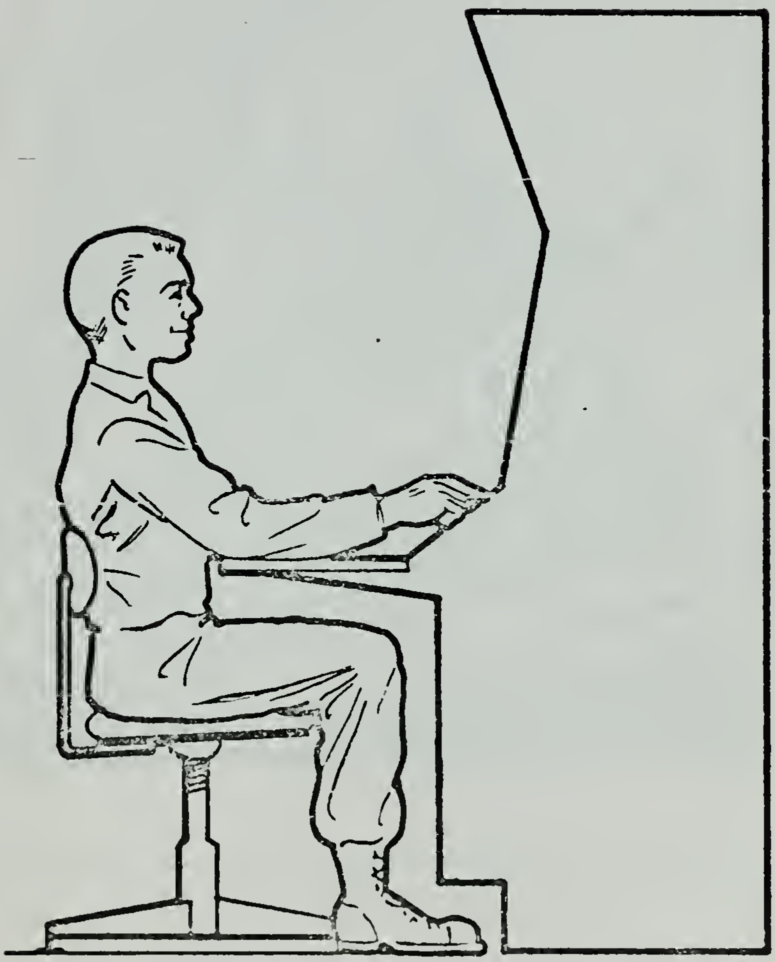


Figure 24. EXAMPLE OF VERTICAL/STACKED SEGMENTS

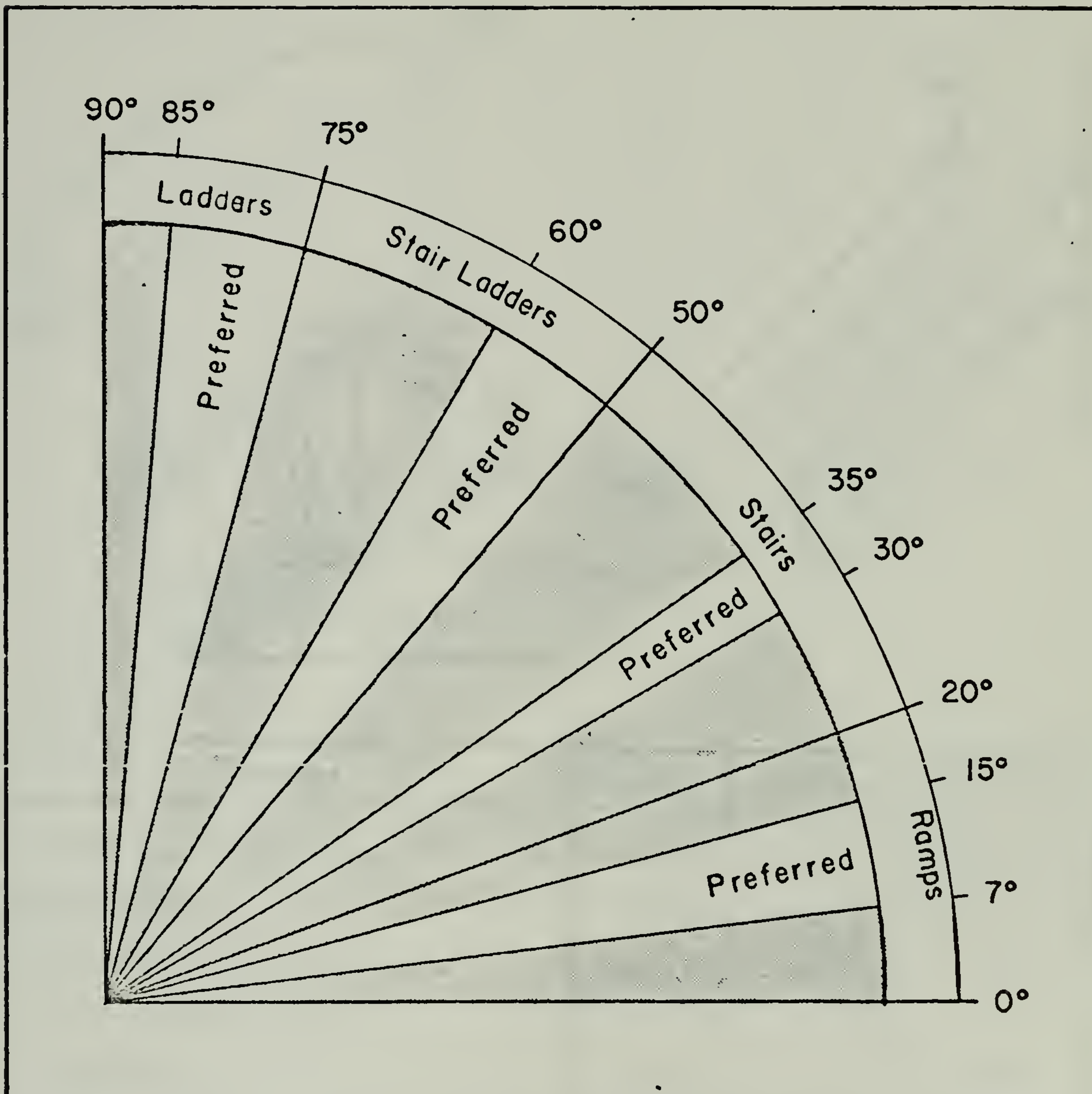
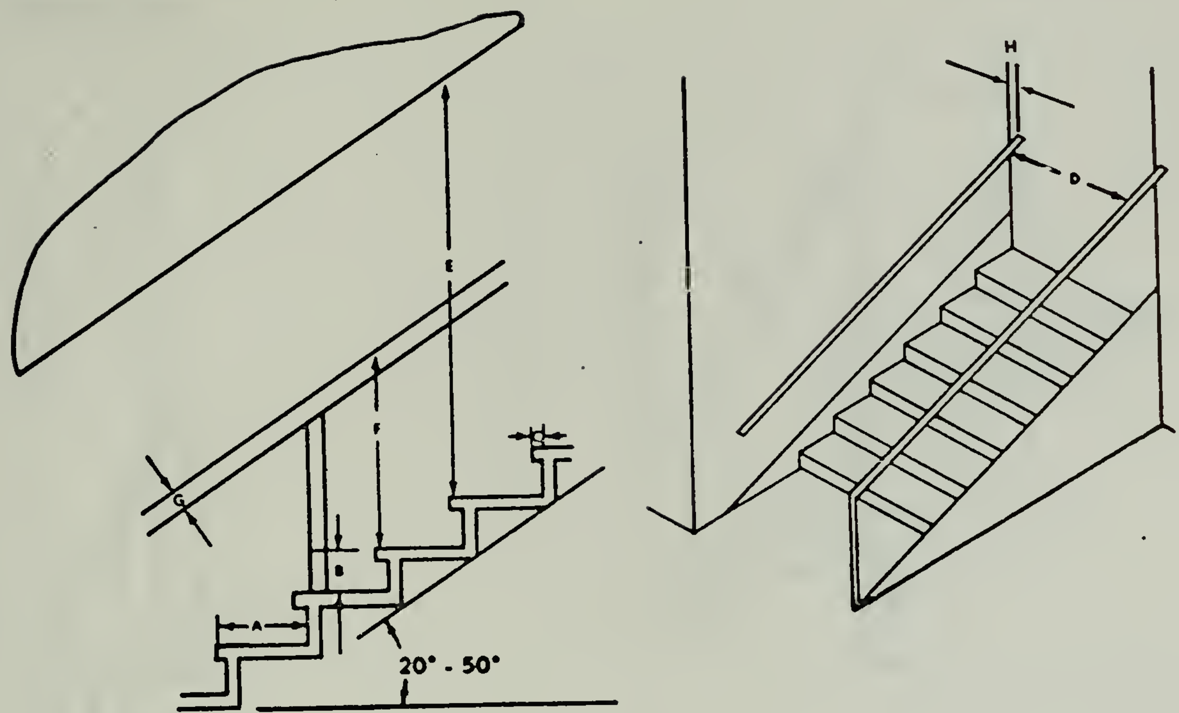
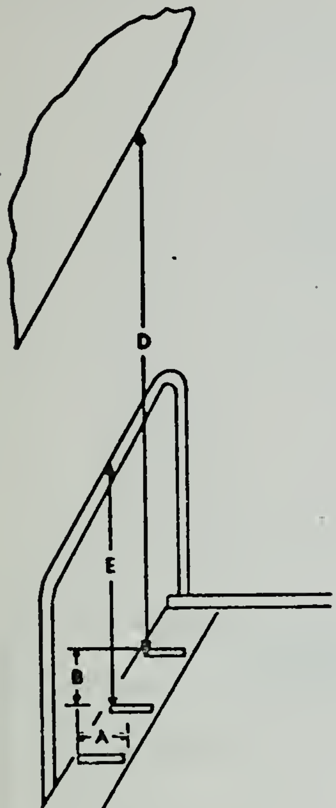


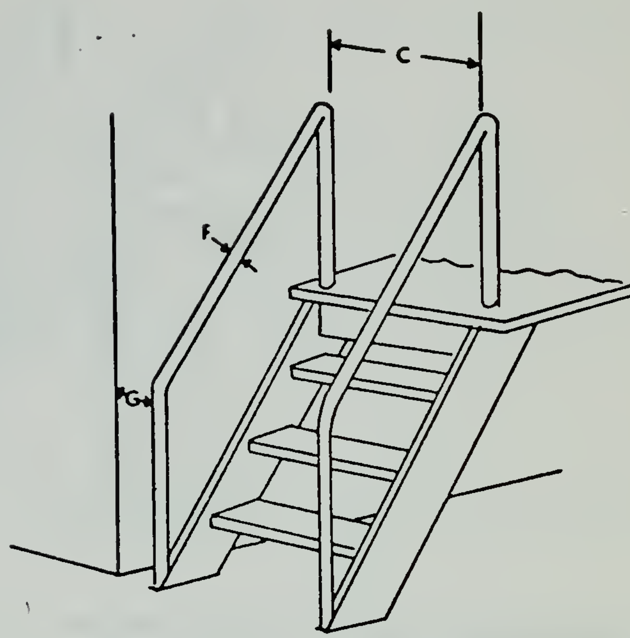
Figure 25. TYPE OF STRUCTURE IN RELATION TO ANGLE OF ASCENT



DIMENSION		MINIMUM	MAXIMUM	RECOMMENDED
A	Tread depth (including nosing)	9.50"	12.00"	11.00" - 12.00"
B	Riser height	5.00"	8.00"	6.50" - 7.00"
C	Depth of nosing (where applicable)	0.75"	1.50"	1.00"
D	Width (handrail to handrail):			
	One-way stairs	30.00"	---	36.00"
	Two-way stairs	48.00"	---	51.00"
E	Overhead clearance	76.00"	---	78.00"
F	Height of handrail (from leading edge of tread)	30.00"	36.00"	33.00"
G	Handrail diameter	1.25"	3.00"	1.50"
H	Rail clearance from wall	1.75"	---	3.00"

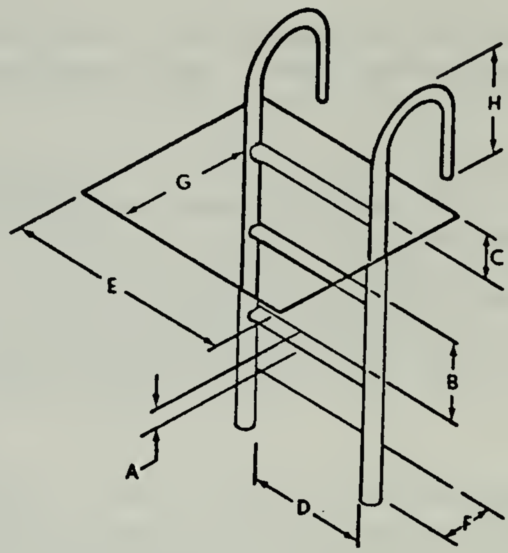
Figure 26. STAIR DIMENSIONS





DIMENSION		MINIMUM	MAXIMUM	RECOMMENDED
A	Tread depth range:			
	For 50° rise	6.00"	10.00"	8.50"
	For 75° rise (open ladders only)	3.00"	5.50"	4.00"
B	Riser height	7.00"	12.00"	9.00"
C	Width (handrail to handrail)	21.00"	24.00"	22.00"
D	Overhead clearance	68.00"	---	76.00"
E	Height of handrail (from leading edge of tread)	34.00"	37.00"	35.00"
F	Handrail diameter	1.25"	3.00"	1.50"
G	Rail clearance from wall	2.00"	---	3.00"

Figure 27. STAIR-LADDER DIMENSIONS



DIMENSION		MINIMUM	MAXIMUM	RECOMMENDED
A	Rung thickness:			
	Wood	1.125"	1.50"	1.40"
	Protected metal	0.75"	1.50"	1.40"
	Corrosive metal	1.00"	1.50"	1.40"
B	Rung spacing	9.00"	16.00"	12.00"
C	Height, rung to landing	6.00"	Rung Spacing	Rung Spacing
D	Width between stringers	12.00"	---	18.00" - 21.00"
E	Climbing clearance width	24.00"	---	30.00"
	Clearance depth:			
	F In back of ladder	6.00"	---	8.00"
	G On climbing side (range)	36.00" for 75° to 30.00" for 90°		
H	Height of stringer above landing	33.00"	---	36.00"

Figure 28. FIXED-LADDER DIMENSIONS

material conforming with specification MIL-W-5044 applied in accordance with specification MIL-W-5050. Stair ladders shall be of metal construction. Handrails shall have nonslip surfaces.

5.7.7.4 Fixed Ladders. - Fixed ladders should be designed to conform with the recommended dimensions in Figure 28. In no instance shall the dimensions exceed the specified minima or maxima. Fixed ladders which are used to provide access to multiple levels should be offset at each successive level. Guardrails should be provided around the opening at the top of each fixed ladder. Safety caging should be provided around fixed ladders which are more than 20 feet (6.1m) high.

5.7.7.5 Ramps

5.7.7.5.1 Cleating. - Where special environmental conditions require cleating of pedestrian ramps, the cleats should be spaced 14 inches (35cm) apart and extend from handrail to handrail at right angles to the line of traffic.

5.7.7.5.2 Mixed Traffic. - When a ramp is required for both pedestrian and vehicle traffic, the vehicle surface should be located in the center of the ramp, with the pedestrian surface next to the handrails. (A vehicle ramp with an adjacent pedestrian stairway is preferred for this situation.)

5.7.7.6 Personnel Platforms and Work Areas. - The surfaces of exterior personnel platforms and work areas shall be constructed of open metal grating. Exterior personnel platforms for which utilization of open grating is impractical, and interior walkways shall be treated with nonskid material conforming to specification MIL-W-5044, applied in accordance with specification MIL-W-5050. All open sides of personnel platforms shall be equipped with guardrails (with intermediate rails), with a top rail height not less than 42 inches (107cm) and a toeboard or guard screen not less than 3 inches (76mm) in height. Hand holds shall be furnished where needed. The distance between the platform edge and the centerline of the railing should not exceed 2-1/2 inches (64mm).

5.7.7.7 Elevators, Inclinators and Hydraulic-Operated Work Platforms. - Where these items are required, the following shall be provided:

a. Maximum load signs shall be used and located where they can be easily seen.

b. Guards shall be used on the controls to prevent accidental operation of the lift.

c. Limit stops shall be used to prevent injury to personnel and damage to equipment.

d. In case of failure of the lift mechanism, an automatic fail-safe brake or other self-locking device shall be engaged. Provision for manually lowering the platform or elevator should be provided when feasible.

e. For open platforms, provisions of 5.7.7.6 shall apply.

5.7.8 Ingress and Egress

5.7.8.1 Doors. - Vertical and sliding doors shall never be installed as the only personnel exit from a compartment. When a sliding door is used, a separate hinged door in the sliding door should be provided for personnel use. Fixed equipment shall be at least three inches (7.6cm) from the swept area of hinged doors.

5.7.8.2 Hatches

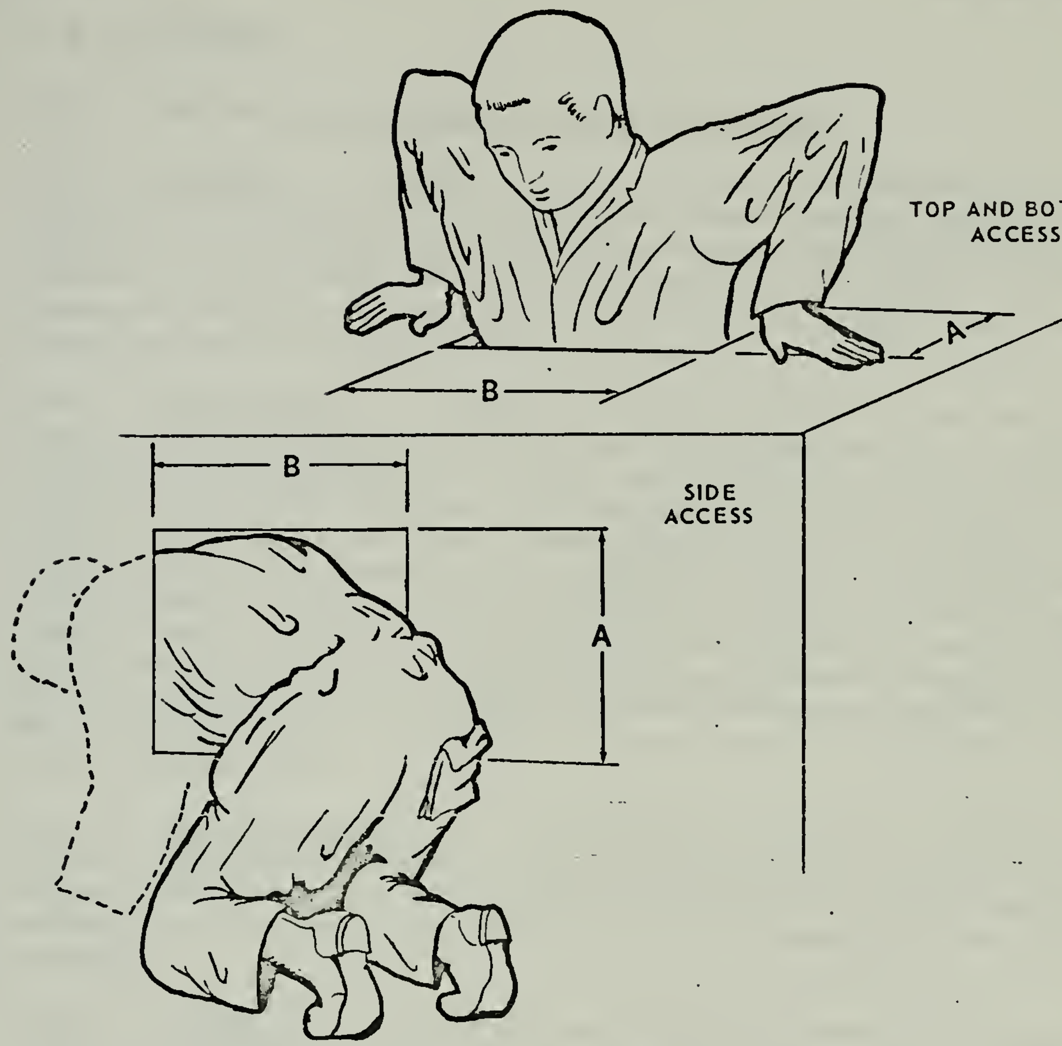
5.7.8.2.1 Configuration. - Wall hatches shall be flush with the floor where structural considerations will permit this arrangement. Hatches shall open with a single motion of the hand or foot.

5.7.8.2.2 Force Requirements. - When a handle is used for unlocking a hatch, the unlocking force required shall not exceed 20 pounds (9.07 kg). Hatches placed in the overhead position should require no more than 50 pounds (22.7 kg) force for opening and should be operable by a suitably equipped and clothed user with 5th percentile arm and hand strength. The force of gravity should be used, where possible, for ease of opening.

5.7.8.2.3 Dimensions. - Hatches shall accommodate suitably equipped and clothed user personnel in terms of limiting dimensions (see 5.6.3.2) for location and operability, and gross dimensions (see 5.6.3.1) for size and passage factors. Where personnel must carry equipment through the hatch, allowance shall be made for clearance of suitably clothed 95th percentile hands and/or arms, as applicable. Where possible, hatch dimensions shall conform to the requirements of 5.7.8.3.

5.7.8.3 Whole-Body Access. - Dimensions for rectangular access openings for body passage shall be no less than those dimensions shown in Figure 29. Minimum diameter for circular hatches shall be 30 inches (76 cm). Where rescue of personnel may be required because of environmental hazards (e.g., toxic fumes) within the work place, larger access openings for two-man ingress and egress may be necessary. Where "step down" through a top access exceeds 27 inches (69 cm), appropriate foot rests or steps shall be provided.

5.7.9 Equipment Colors



DIMENSIONS	A. WIDTH		B. LENGTH	
CLOTHING	LIGHT	BULKY	LIGHT	BULKY
TOP AND BOTTOM ACCESS	13"	16"	23"	27"
SIDE ACCESS	26"	29"	30"	34"

Figure 29. WHOLE BODY ACCESS OPENING

5.8 ENVIRONMENT

5.8.1 Heating, Ventilating, and Air Conditioning

5.8.1.1 Heating. - Heating shall be provided within mobile personnel enclosures utilized for detail work or occupied during extended periods of time to maintain interior dry bulb temperature above 50°F (10°C). A minimum of 68°F (20°C) shall be maintained within permanent and semi-permanent facilities. Heating systems shall be designed such that hot air discharge is not directed on personnel.

5.8.1.2 Ventilating. - Adequate ventilation shall be assured by introducing a minimum of thirty cubic feet per minute per man into any personnel enclosure; approximately two-thirds should be outside air. Air shall be moved past the man at a rate less than 100 feet (30m) per minute -- 65 feet (20m) per minute if possible. Under chemical-bacteriological or radiological conditions, ventilation requirements should be modified as required. Ventilation or other protective measures shall be provided to keep gases, vapors, dust, and fumes below the maximum allowable concentrations specified in the American Conference of Governmental Industrial Hygienists Threshold Limit Values. Intakes for ventilation systems shall be so located as to minimize the introduction of contaminated air from such sources as exhaust pipes, etc.

5.8.1.3 Air Conditioning. - Air conditioning shall be provided if the effective temperature within personnel enclosures utilized for detail work during extended periods exceeds 85°F (see Figure 30). Air conditioning systems shall be designed such that cold-air discharge is not directed on personnel.

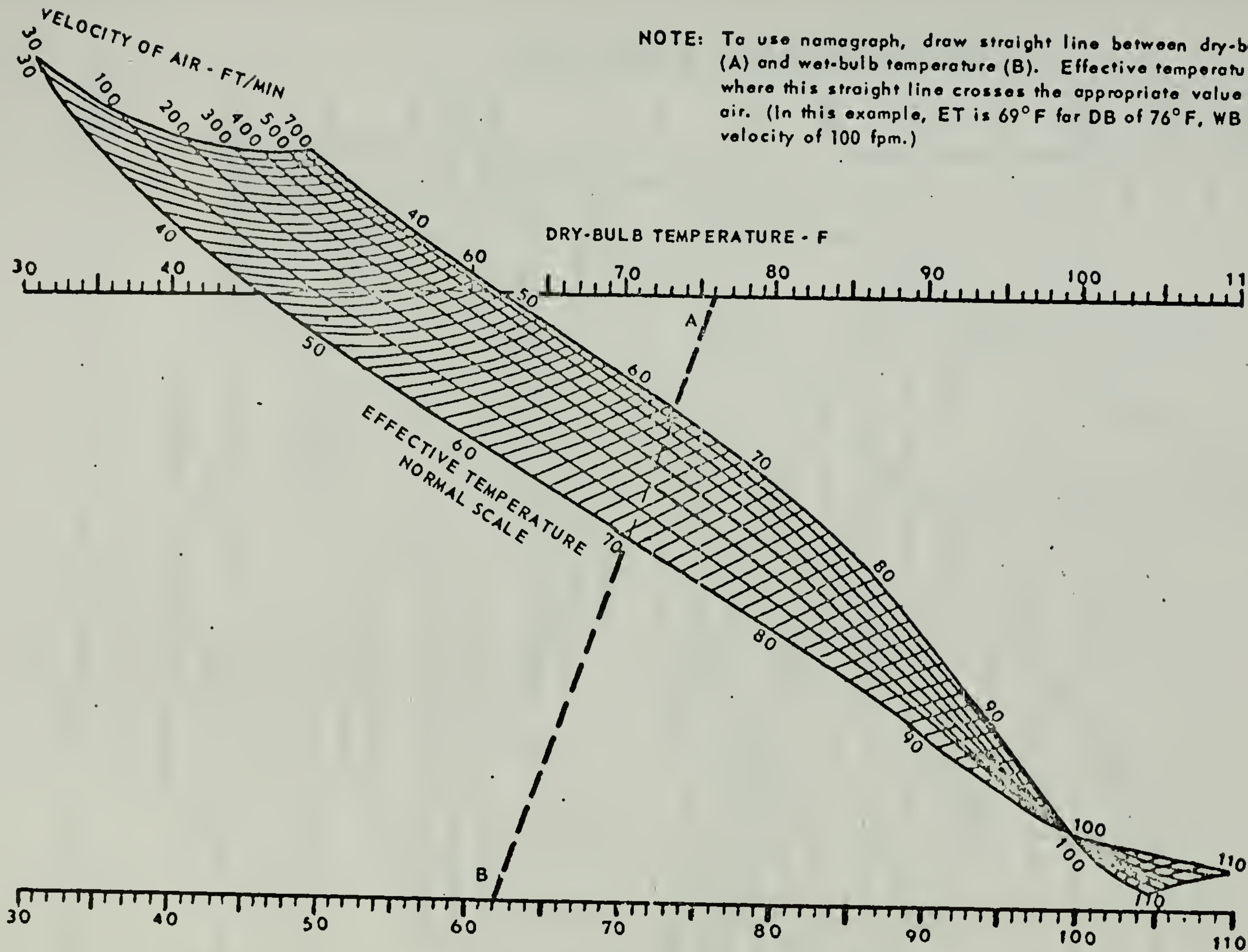
5.8.1.4 Humidity. - Humidity values should approximate 45 percent relative humidity at 70°F. (21°C). This value should decrease with rising temperatures, but should remain above 15 percent to prevent irritation and drying of body tissues, e.g., eyes, skin, and respiratory tract (See Figure 31).

5.8.1.5 Temperature Uniformity. - In providing for heating and cooling of enclosed areas, it is important that the temperature of the enclosed area be held relatively uniform. The temperature of the air at floor level and at head level should not differ significantly (maximum of 10 F°).

5.8.1.6 Personal Equipment Thermal Control. - When special protective clothing or personal equipment, including full and partial pressure suits, fuel handler suits, body armor, arctic clothing and temperature regulated clothing are required and worn, a comfort micro climate between 68°F (20°C), 14mm Hg ambient water vapor pressure and 95°F (35°C), 3mm Hg ambient water vapor pressure shall be maintained by heat transfer systems.

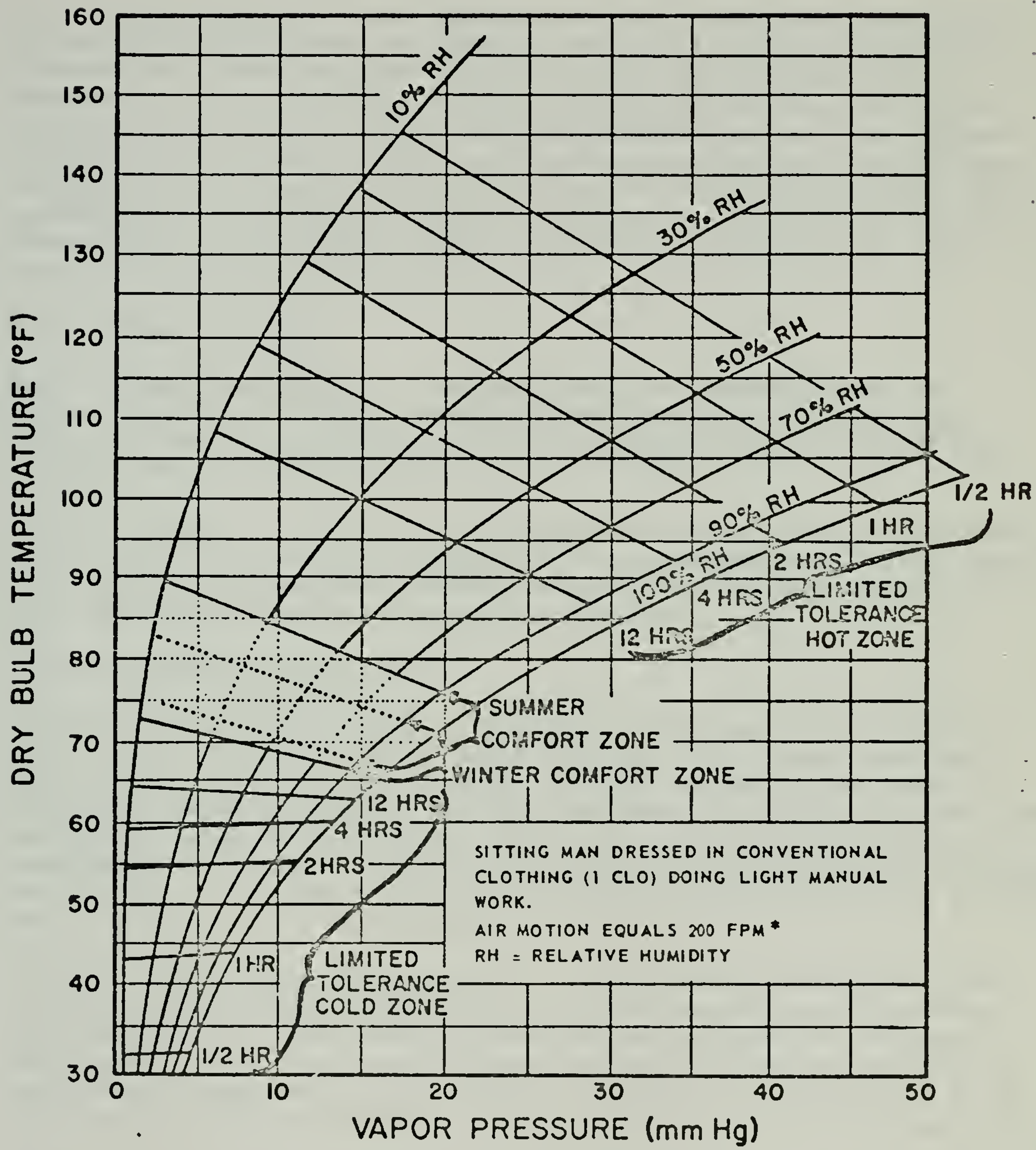
5.8.1.7 Thermal Tolerance and Comfort Zones. - Temperature and humidity exposure should not exceed the tolerance limits given in Figure 31 when corrected for air flow rate (Figure 30).

NOTE: To use namograph, draw straight line between dry-bulb temperature (A) and wet-bulb temperature (B). Effective temperature is indicated where this straight line crosses the appropriate value for velocity of air. (In this example, ET is 69°F for DB of 76°F, WB of 62°F and air velocity of 100 fpm.)



Clothing: Customary indoor clothing. Activity: Sedentary or light muscular work. Heating Methods: Convection type, i.e., warm air, direct steam or hot water radiators, plenum systems.

Figure 30. EFFECTIVE TEMPERATURE



*AIR MOTION EQUALS 200 FPM FOR TOLERANCE ZONES AND 20 FPM FOR COMFORT ZONES.

Figure 31. SUMMER AND WINTER COMFORT ZONES AND THERMAL TOLERANCE FOR INHABITED COMPARTMENTS

5.8.2 Illumination. - Where equipment is to be used in enclosures and is not subject to blackout or special low-level lighting requirements, illumination levels shall be as specified by Table VIII and shall be distributed so as to reduce glare and specular reflection. Capability for dimming shall be provided. Adequate illumination shall be provided for maintenance tasks. General and supplementary lighting shall be used as appropriate to insure that illumination is compatible with each task situation. Portable lights should be provided for personnel performing visual tasks in areas where fixed illumination is not provided. For display lighting, see Table IX.

5.8.3 Acoustical Noise

5.8.3.1 Hazardous Noise. - Equipment shall not generate noise in excess of maximum allowable levels prescribed by HEL Standard S-1-63, AFR 160-3, BuShips Specification S-1-10, BUMEDINST 6260.6, MIL-STD-740, or MIL-A-8806, as applicable.

5.8.3.2 Control. - Noise generation and penetration shall be controlled to the extent that acoustic energy will not cause personnel injury, interfere with voice or any other communications, cause fatigue, or in any other way degrade over-all system effectiveness.

5.8.3.3 Speech Communication

5.8.3.3.1 Articulation Index. - Facility and equipment noise shall be controlled to levels that will permit necessary voice communications. Where such communication is extremely critical and the system does not yet exist, acoustic acceptability shall be based on the Articulation Index determined by the 20-Band Method. Where only sentences need to be recognized, the AI shall be at least 0.3; where isolated words are critical, the AI shall be at least 0.5; and where separate syllables must be intelligible, the AI shall be at least 0.7.

5.8.3.3.2 Speech Interference Level. - If the noise spectrum is relatively flat and steady, and communication requirements do not exceed an estimated AI of 0.5, acoustic acceptability may be based on the Speech Interference Level. For example, where normal voice communication is required at a distance of 9 feet (2.7m), the SIL should not exceed 45 dB; at 18 feet (5.5m), the SIL should not exceed 40 dB; etc. (see Figure 32).

5.8.3.3.3 Maintenance Areas. - In areas where maintenance requires occasional, non-electrically aided voice communication, the noise level generated by equipment shall not exceed the sound pressure levels shown for various octave bands on Noise Criterion (NC) Curve 70 in Figure 33. Where intermittent direct communication and occasional telephone conversation are necessary, the level should not exceed NC-60.

TABLE VIII. SPECIFIC TASK ILLUMINATION REQUIREMENTS

ILLUMINATION LEVELS	FOOT CANDLES*	
WORK AREA OR TYPE OF TASK	RECOMMENDED	MINIMUM
Assembly, missile component	100	50
Assembly, general		
coarse	50	30
medium	75	50
fine	100	75
precise	300	200
Bench work		
rough	50	30
medium	75	50
fine	150	100
extra fine	300	200
Business machine operation (calculator, digital, input, etc.)	100	50
Console surface	50	30
Corridors	20	10
Circuit diagram	100	50
Dials	50	30
Electrical equipment testing	50	30
Emergency lighting	--	3
Gages	50	30
Hallways	20	10

* As measured at the task object or 30 inches above the floor.

(Continued)

TABLE VIII (Continued). SPECIFIC TASK ILLUMINATION REQUIREMENTS

WORK AREA OR TYPE OF TASK	FOOT CANDLES* RECOMMENDED	FOOT CANDLES* MINIMUM
Inspection tasks, general:		
rough	50	30
medium	100	50
fine	200	100
extra fine	300	200
Machine operation, automatic	50	30
Meters	50	30
Missiles:		
repair and servicing	100	50
storage areas	20	10
general inspection	50	30
Office work, general	70	50
Ordinary seeing tasks	50	30
Panels:		
front	50	30
rear	30	10
Passageways	20	10
Reading:		
large print	30	10
newsprint	50	30
handwritten reports, in pencil	70	50
small type	70	50
prolonged reading	70	50
Recording	70	50
Repair work:		
general	50	30
instrument	200	100

* As measured at the task object or 30 inches above the floor.

(Continued)

TABLE VIII (Concluded). SPECIFIC TASK ILLUMINATION REQUIREMENTS

WORK AREA OR TYPE OF TASK	FOOT CANDLES* RECOMMENDED	FOOT CANDLES* MINIMUM
Scales	50	30
Screw fastening	50	30
Service areas, general	20	10
Stairways	20	10
Storage:		
inactive or dead	5	3
general warehouse	10	5
live, rough or bulk	10	5
live, medium	30	20
live, fine	50	30
Switchboards	50	30
Tanks, containers	20	10
Testing:		
rough	50	30
fine	100	50
extra fine	200	100
Transcribing and tabulation	100	50

NOTE: Some unusual inspection tasks may require up to 1,000 foot candles of light.

NOTE: As a guide in determining illumination requirements the use of a steel scale with 1/64 inch divisions requires 180 foot candles of light for optimum visibility.

* As measured at the task object or 30 inches above the floor.

TABLE IX. RECOMMENDATIONS FOR DISPLAY LIGHTING

CONDITION OF USE	LIGHTING TECHNIQUE	BRIGHTNESS OF MARKINGS (ft – L)	BRIGHTNESS ADJUSTMENT
Indicator reading, dark adaptation necessary	Red flood, indirect, or both, with operator choice	0.02-0.1	Continuous throughout range
Indicator reading, dark adaptation not necessary but desirable	Red or low-color-temperature white flood, indirect, or both, with operator choice	0.02-1.0	Continuous throughout range
Indicator reading, dark adaptation not necessary	White flood	1.0-20.0	Fixed or continuous
Panel monitoring, dark adaptation necessary	Red edge lighting, red or white flood, or both, with operator choice	0.02-1.0	Continuous throughout range
Panel monitoring, dark adaptation not necessary	White flood	10.0-20.0	Fixed or continuous
Possible exposure to bright flashes, restricted daylight	White flood	10.0-20.0	Fixed
Chart reading, dark adaptation necessary	Red or white flood with operator choice	0.1-1.0 (on white portion of chart)	Continuous throughout range
Chart reading, dark adaptation not necessary	White flood	5.0-20.0	Fixed or continuous

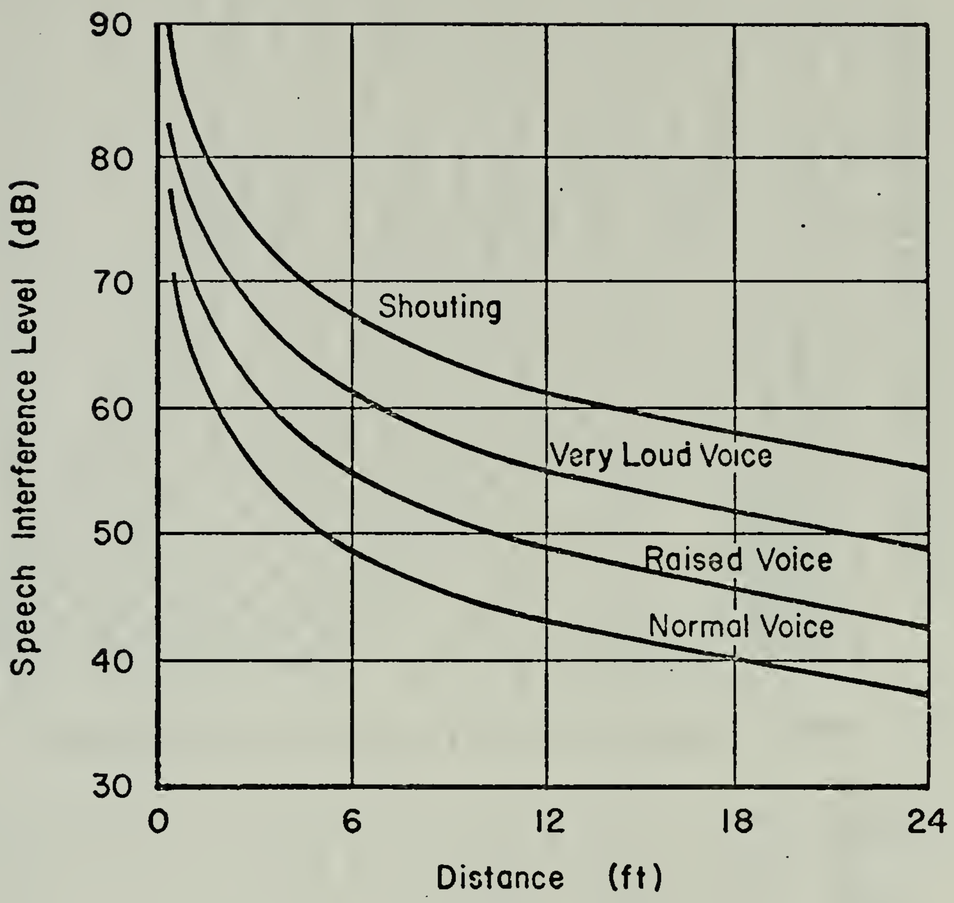


Figure 32. SPEECH INTERFERENCE LEVELS FOR VARIOUS DISTANCES AND VOICE LEVELS

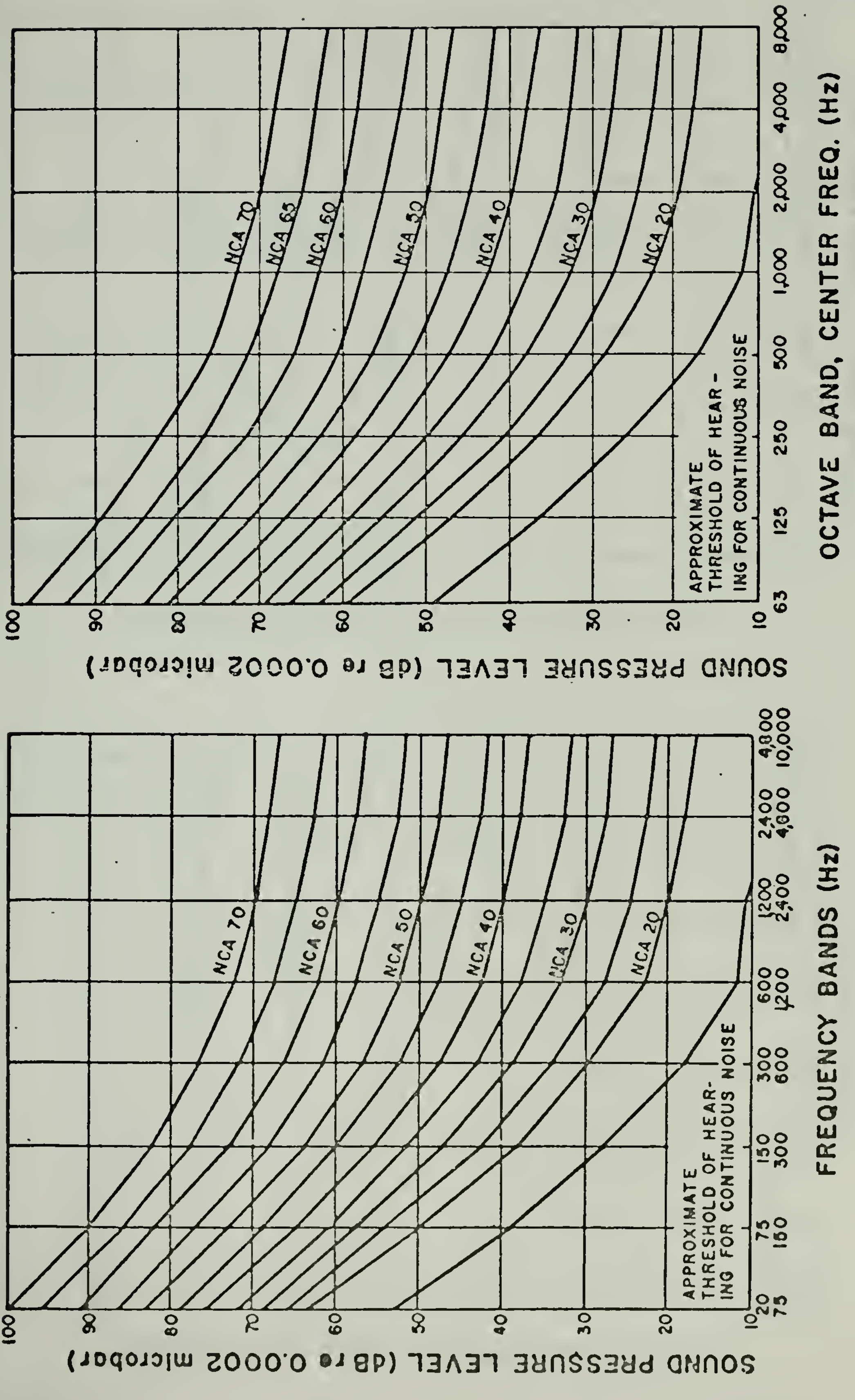
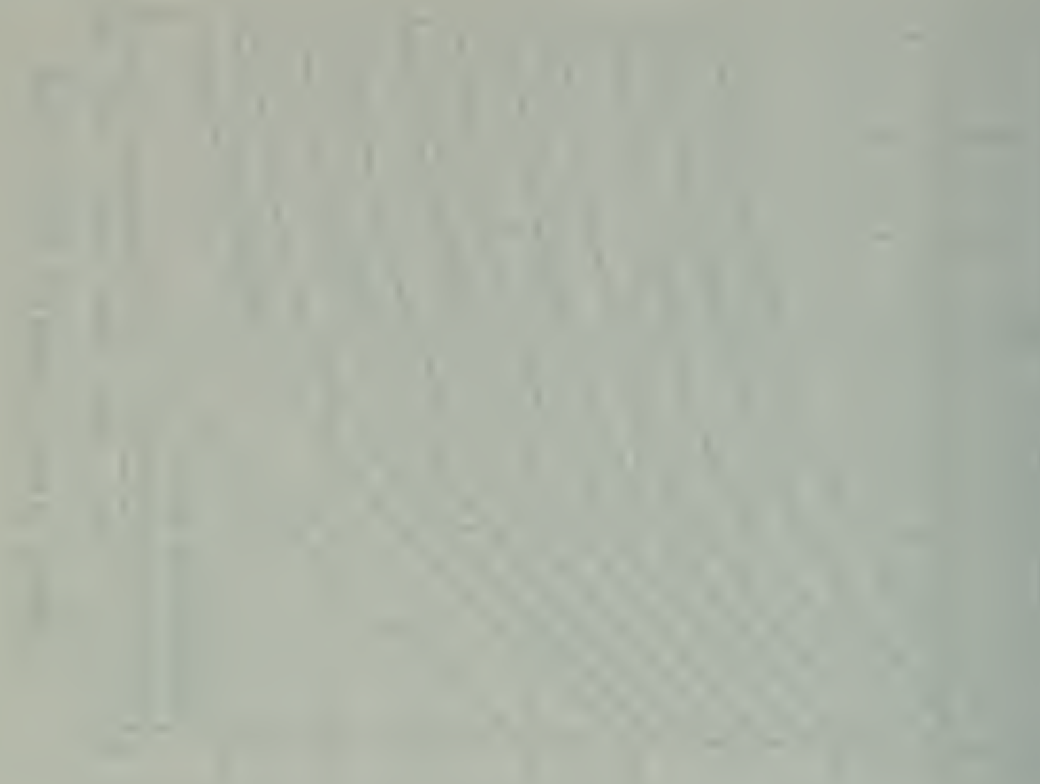


Figure 34. NOISE CRITERIA. ALTERNATE (NCA) CURVES FOR SPEECH COMMUNICATION



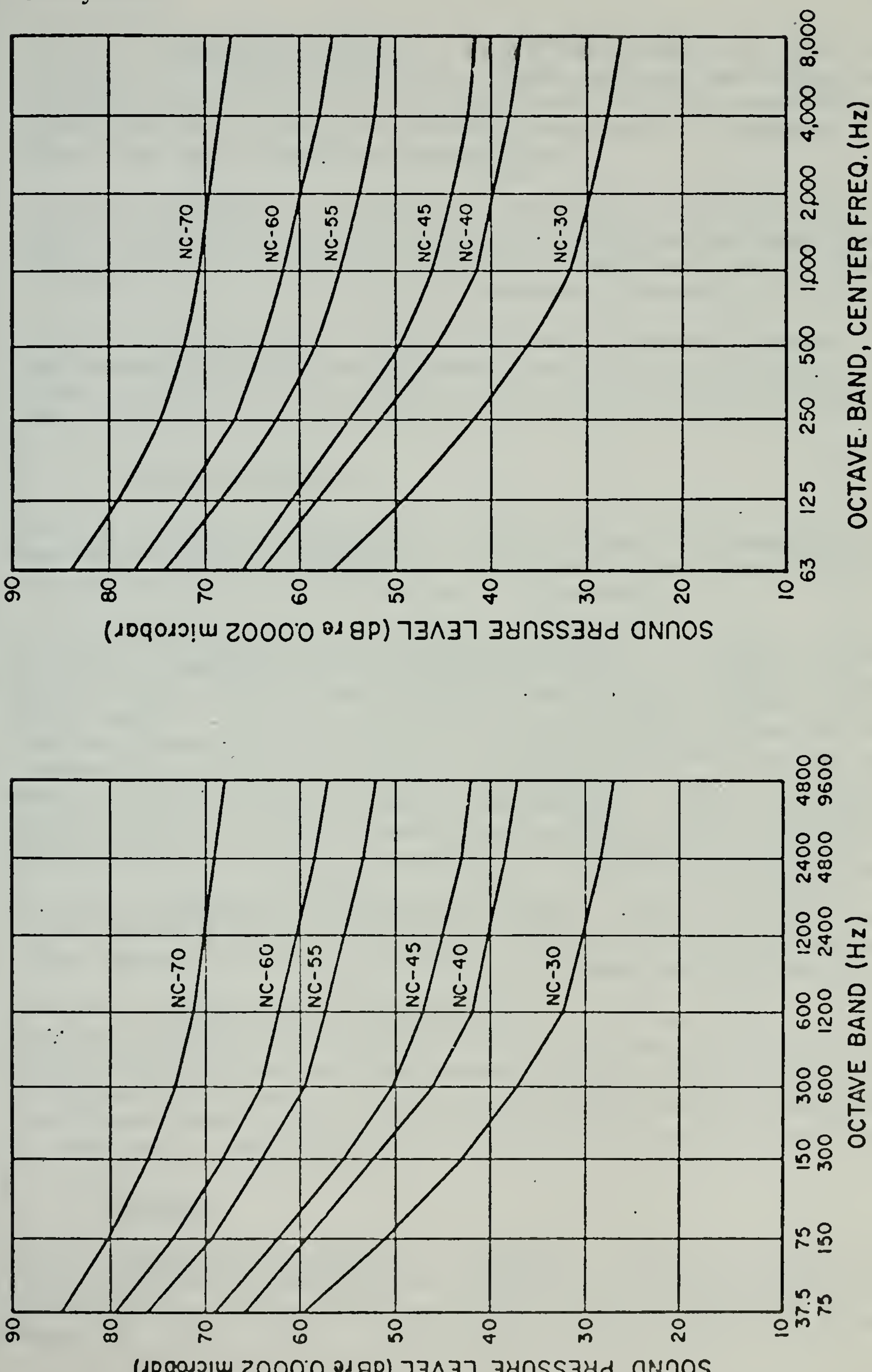
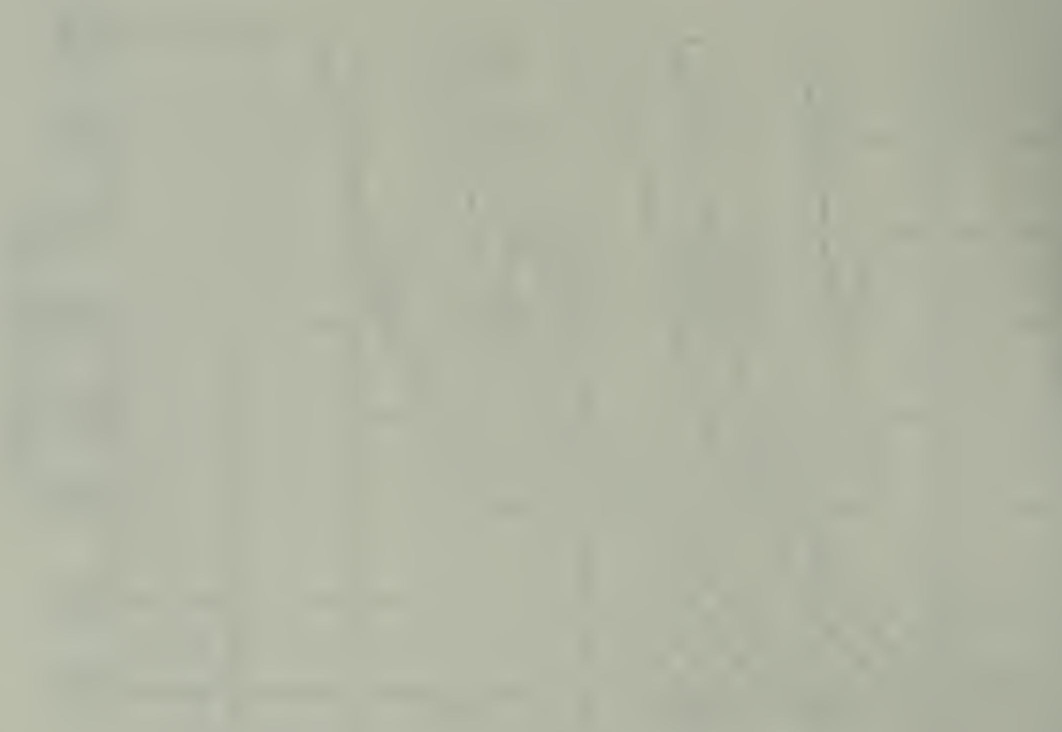


Figure 33. NOISE CRITERIA (NC) CURVES FOR SPEECH COMMUNICATION



5.8.3.3.4 Operational Areas. - In offices, shops, and other areas where equipment is used regularly by operating personnel and continuous direct communication is required, the noise level shall not exceed NC-60 in Figure 33. Where frequent telephone communication is necessary in such areas, the level should not exceed NC-45.

5.8.3.3.5 Aircraft. - In aircraft where high intelligibility is the governing factor in determining the allowable sound pressure levels, the Noise Criteria, Alternate, 65 dB curve is desirable and the Noise Criteria, Alternate, 70 dB curve will be the maximum allowable (see Figure 34).

5.8.3.3.6 Other Areas. - The noise level in general offices, command and control centers, drafting rooms, and similar areas shall not exceed NC-40 in Figure 33. In areas where extreme quiet is required, the level should not exceed NC-30.

5.8.3.4 Facility Design

5.8.3.4.1 General Provision. - In the design of a workspace or facility, the ambient noise level shall be controlled to the optimum extent feasible through effective sound reduction or attentuation.

5.8.3.4.2 Attenuation by Materials and Layout. - Acoustic materials with high sound-absorption coefficients shall be provided as necessary in the construction of floors, walls, and ceiling to effect the required sound control. In the physical design and layout of rooms and work stations, excessive noise shall be attenuated by such means as staggered construction of walls, staggering of doors in corridors or between rooms, and use of thick-paned or double-paned windows. Where applicable, sound baffles consisting of acoustical materials of appropriate size, shape and design shall be provided in proximity to noise-generating sources.

5.8.3.4.3 Reduction of Reverberation Time. - The acoustical treatment of facilities shall be sufficient to reduce reverberation time to the limits shown in Figure 35 with respect to space and intended use.

5.8.3.4.4 Acceptable Sound-Conditioning. - The average room sound absorption coefficient shall be at least 0.20, but should not exceed 0.50. When an existing room is to be improved acoustically, the total room absorption coefficient (or average coefficient) should be increased at least three times in order that the change in acoustical conditions will be definite and unmistakable.

5.8.4 Vibration

5.8.4.1 Whole-Body Vibrations. - Facilities and facility equipment shall be designed to preclude the transmission of whole body vibrations to personnel in the amplitude and frequency range above Line AA in Figure 36.

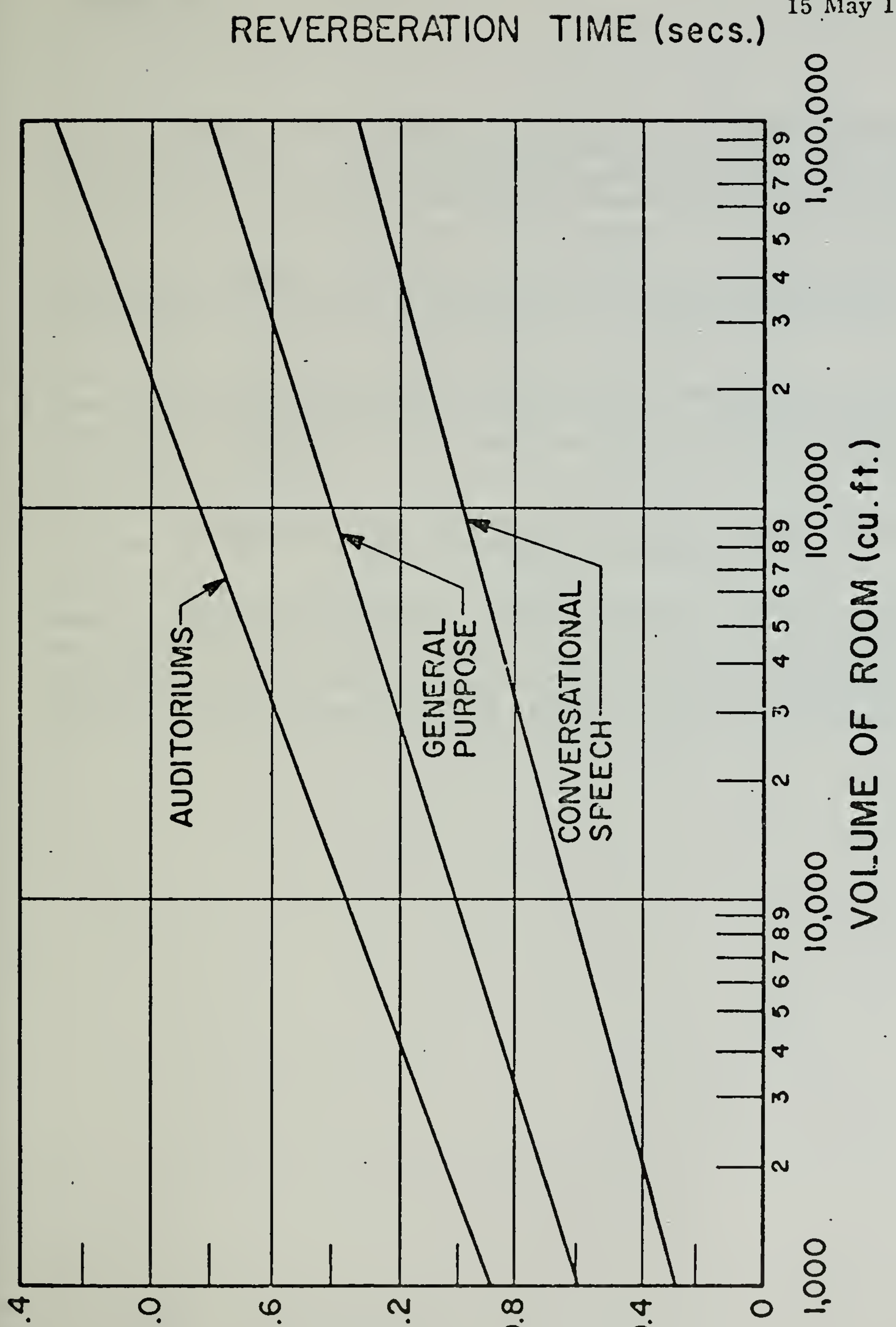


Figure 35. RANGE OF ACCEPTABLE REVERBERATION TIME

5.8.4 Vibration

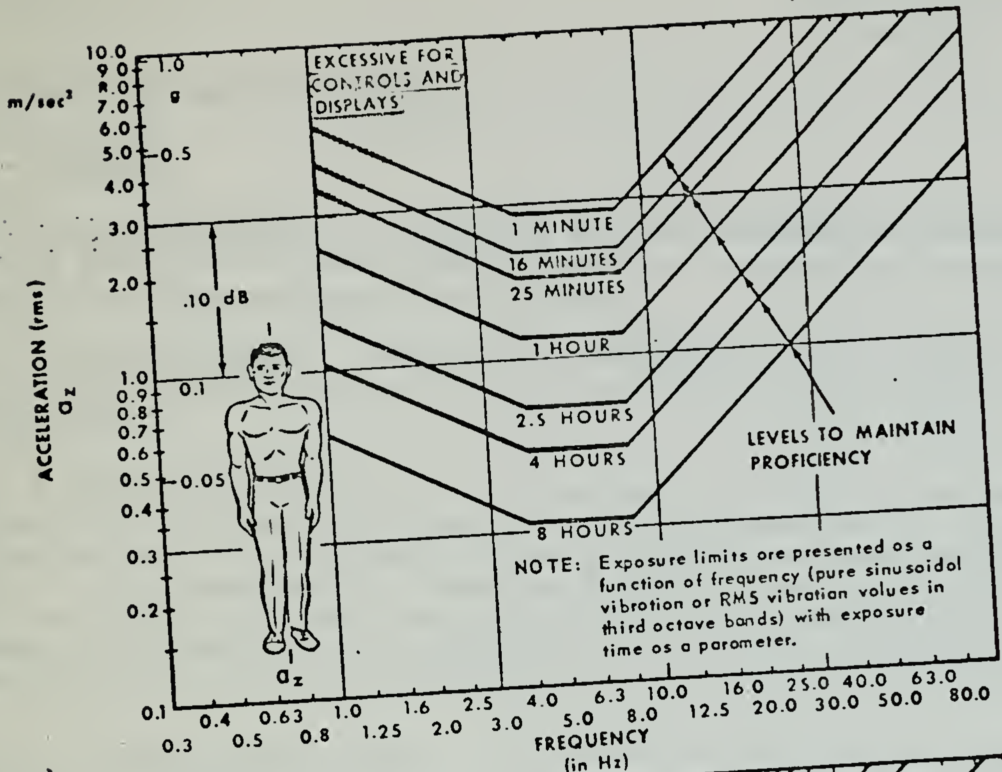
5.8.4.1 Whole Body Vibration. - Facilities and facility equipment shall be designed to control the transmission of whole body vibration to levels that will permit safe operation and maintenance as shown in Figure 36. In the case of multi-directional vibration, each direction is to be evaluated independently with respect to the limits presented.

5.8.4.1.1 Safety Limits. - In order to protect Human Health, whole body vibration shall not exceed twice the acceleration values shown on Figure 36 for the time and frequencies indicated.

5.8.4.1.2 Proficiency Levels. - Where proficiency is required for operational and maintenance tasks, whole body vibration shall not exceed the acceleration values shown on Figure 36 for the time and frequencies indicated.

5.8.4.1.3 Comfort Level. - Where comfort is to be maintained, the acceleration values (Figure 36) shall be divided by 3.15.

5.8.4.2 Equipment Vibrations. - Where whole body vibrations of the human operator or parts of his body are not a factor, equipment should be designed so that oscillations will not impair human performance with respect to control manipulations or the readability of numerals or letters. Such equipment shall be designed to preclude vibrations in the shaded area of the upper curve of Figure 36.



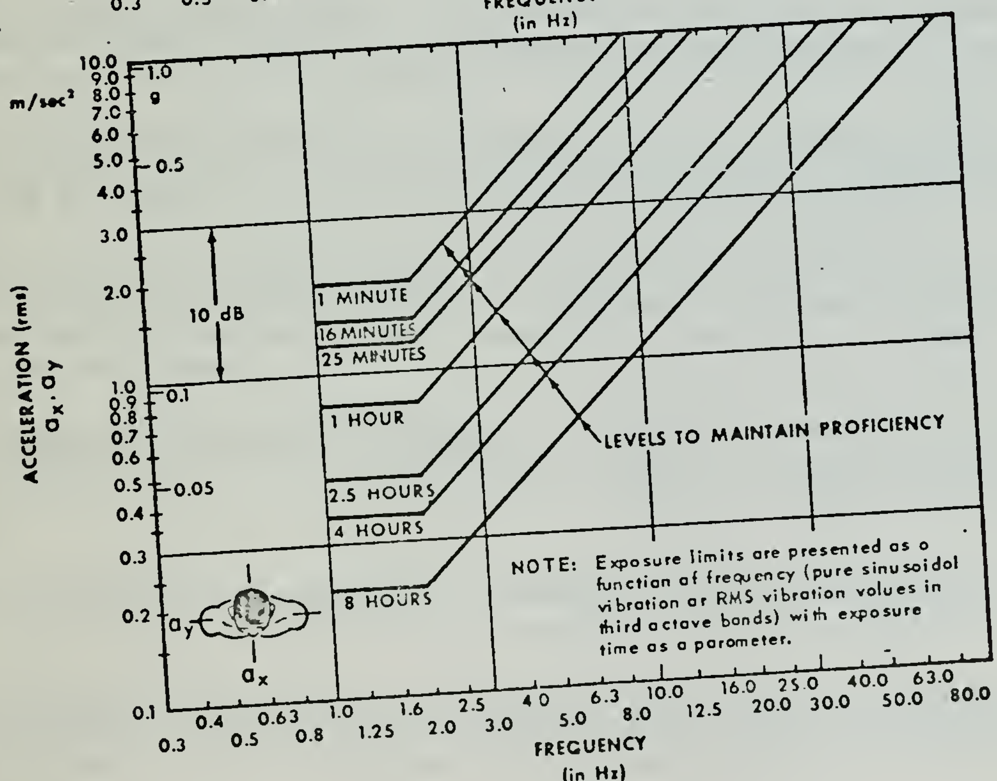


Figure 36. VIBRATION EXPOSURE CRITERIA FOR LONGITUDINAL (UPPER CURVE) AND TRANSVERSE (LOWER CURVE) DIRECTIONS WITH RESPECT TO BODY AXIS

5.9 DESIGN FOR MAINTAINABILITY

5.9.1 General

5.9.1.1 Standardization. - Equipment shall be designed to incorporate standard parts to the maximum extent feasible. Standard parts should meet the human engineering criteria herein.

5.9.1.2 Special Tools. - Special tools required for operational adjustment should be securely mounted within the equipment in a readily accessible location.

5.9.1.3 Modular Replacement. - The equipment shall be designed and constructed for replacement of small electronic assemblies by replacing modular packages in accordance with the provisions contained in MIL-E-11991. All equipment shall be designed in such a manner that rapid and easy removal and replacement can be accomplished by one man where structural and functional limitations permit, within the weight limitations contained in paragraph 5.9.11.3.

5.9.1.4 Grouping of Functions. - The number of inputs to and outputs from each unit shall be kept to a minimum by grouping functions so as to minimize criss-crossing of signals.

5.9.1.5 Separate Adjustability. - Functions shall be so unitized that it will be possible to check and adjust each unit separately, except where this would be inconsistent with established maintenance concepts.

5.9.1.6 Malfunction Identification. - Equipment shall be designed to facilitate rapid and positive fault detection and isolation of defective equipment modules, assemblies, and components to permit their prompt removal and replacement.

5.9.1.7 Removal, Replacement and Repair. - Equipment shall be designed for rapid and easy removal, replacement, or repair of malfunctioning units by one individual, unless such design is structurally or functionally not feasible.

5.9.1.8 Assembly and Disassembly. - Equipment shall be designed to enhance the ease with which it can be assembled and disassembled.

5.9.1.9 Clothing Constraints. - When applicable, equipment shall be designed so that it can be removed, replaced, and repaired by personnel wearing personal and special purpose clothing and equipment.

5.9.1.10 Foolproof Design. - Efforts to attain standardization shall be accompanied by provisions to facilitate identification to preclude improper mounting and installation. These provisions shall include:

a. Physical measures to preclude interchange of units or components of a same or similar form that are not in fact functionally interchangeable.

b. Physical measures to preclude improper mounting of units or components.

c. Measures (e.g., coding) to facilitate identification and interchange of interchangeable units or components.

d. Measures (e.g., alignment pins) to facilitate proper mounting of units and components.

e. Measures to insure that identification, orientation, and alignment provisions include cables and connectors.

5.9.2 Mounting of Components within Units

5.9.2.1 Use of Two Dimensional Surface. - Parts should be mounted in an orderly array on a "two-dimensional" surface, rather than "stacked" one on another (i.e., a lower layer should not support an upper layer).

5.9.2.2 Similarity. - Components of the same or similar form, but different functional properties, shall be mounted with a standard orientation throughout the unit, but shall be readily identifiable and distinguishable, and shall not be physically interchangeable.

5.9.2.3 Delicate Components. - Delicate components shall be located or guarded so that they will not be susceptible to damage while the unit is being handled or maintained.

5.9.3 Adjustment Controls

5.9.3.1 Calibration Adjustments. - Knobs should be selected in preference to screwdriver adjustments whenever frequent adjustment must be performed.

5.9.3.2 Screwdriver Adjustments. - If screwdriver adjustments must be made without the aid of vision, mechanical guides for the screwdriver shaft shall be provided or the screws shall be mounted so that the screwdriver will not move out of position.

5.9.3.3 Reference Scale for Adjustment Controls. - A reference scale or any other appropriate feedback shall be provided for all adjustment controls.

5.9.3.4 Control Limits. - Calibration or adjustment controls which are intended to have a limited degree of motion should be provided with adequate mechanical stops to prevent damage.

5.9.3.5 Sensitive Adjustments. - Sensitive adjustment points shall be located or guarded so that adjustments will not be disturbed inadvertently. Suitable hand or arm support shall be provided near the location to facilitate making the adjustment in all cases where the operator is subjected to disturbing vibrations or acceleration during the adjustment operation.

5.9.3.6 Hazardous Locations. - Internal controls should not be located close to dangerous voltages, rotating machinery, or any other hazards. If such location cannot be avoided, the controls shall be appropriately shielded and labeled.

5.9.4 Accessibility

5.9.4.1 Structural Members. - Structural members of units or chassis shall not prevent access to or removal of components. Replaceable items shall not be placed in a manner which will make them difficult to remove. Where accessibility depends upon removal of panels, cases, and covers, measures shall be taken to insure that such items are not blocked by structural members or other items.

5.9.4.2 Large Parts. - Large parts which are difficult to remove shall be so mounted that they will not prevent convenient access to other parts.

5.9.4.3 Use of Tools and Test Equipment. - Check points, adjustment points, test points, cables, connectors, and labels shall be accessible and visible during maintenance. Sufficient space shall be provided for the use of test equipment and other required tools without difficulty or hazard.

5.9.4.4 Rear Access Units. - Sliding, rotating or hinged units to which rear access is required shall be free to open or rotate their full distance and remain in the open position without being supported by hand. Rear access shall also be provided to plug connectors except where precluded by any other operational requirements.

5.9.4.5 Relative Accessibility. - In determining the relative accessibility of units, those units which are critical to system operation and which require rapid maintenance shall be most accessible. When relative criticality is not a factor, these units requiring most frequent access shall be most accessible.

5.9.4.6 High-Failure-Rate-Items. - The physical arrangement of units and components should be such that high-failure-rate items will be accessible for replacement without moving non-failed components or units. Mechanical replacement items shall be removable with common hand tools and simple handling equipment.

5.9.4.7 Skills. - Access to units maintained by one technician should not require removal of critical equipment maintained by another technician, particularly where highly specialized skills are involved.

5.9.5 Lubrication

5.9.5.1 General. - Units containing mechanical components shall be designed to permit lubrication of the components without disassembling the unit, or they shall not require lubrication for the life of the unit. Extended fittings shall be provided to lubricate parts not readily accessible or visible.

5.9.5.2 Labeling. - Where lubrication is required, the type of lubricant to be used and the frequency of lubrication shall be specified by a label mounted at or near the lube port. A lubrication chart of permanent construction shall be mounted at the operator station of the equipment; individual labels shall not be required when the equipment has only one type of fitting and uses only one type of lubricant.

5.9.6 Unit Cases and Covers

5.9.6.1 Alignment. - Covers or shields through which mounting screws must pass for attachment to the basic chassis of the unit shall have large enough holes to permit the screws to pass without perfect case alignment.

5.9.6.2 Edges and Corners. - Edges and corners on cases and covers shall be rounded or otherwise finished to prevent injury to personnel.

5.9.7 Cases

5.9.7.1 Orientation of Units. - The proper orientation of a unit within its case shall be made obvious, either through design of the case or by means of appropriate labels.

5.9.7.2 Removal of Units. - When practical, cases shall be designed to be lifted from units rather than units lifted from cases.

5.9.7.3 Size. - Cases shall be sufficiently larger than the units they cover to minimize the possibility of damaging wires or other components when the cases are put on or taken off.

5.9.7.4 Guides. - Guides, tracks, and stops shall be provided as necessary to facilitate handling and to prevent damage to units and components, and injury to personnel.

5.9.8 Covers

5.9.8.1 Securing of Covers. - It shall be made obvious when a cover is not secured, even though it may be in place.

5.9.8.2 Instructions. - If the method of opening a cover is not obvious from the construction of the cover itself, instructions shall be permanently displayed on the outside of the cover.

5.9.8.3 Clearance. - Bulkheads, brackets, and other units shall not interfere with removal or opening of covers on units within which work must be performed.

5.9.9 Access Openings and Covers

5.9.9.1 Application. - An access shall be provided whenever frequent maintenance operations would otherwise require removing a case or covering, opening a fitting, or dismantling a component.

5.9.9.2 Self-Supporting Covers. - All access covers that are not completely removable shall be self-supporting in the open position. Accesses (and covers) should be devoid of sharp edges to preclude hand injury and clothing damage.

5.9.9.3 Labeling.-Each access should be labeled with nomenclature for items visible or accessible through it, nomenclature for auxiliary equipment to be used with it and recommended procedures for accomplishing operations. Accesses shall be labeled with warning signs, advising of any hazards existing beyond the access and stating necessary precaution. If instructions applying to a covered item are lettered on a hinged door, the lettering shall be properly oriented to be read when the door is open. Warning notices shall be clear, direct, and attention getting and of 25% larger letter size than any detailed instructions which follow (e.g., Danger! Deadly Shock Hazard! rather than Warning-High Voltage).

5.9.9.4 Physical Access

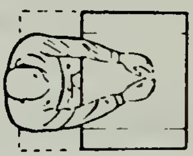
5.9.9.4.1 Arm and Hand Access. - Access openings provided for adjusting and handling interior items shall be sufficiently large to permit the required operations and where possible, provide an adequate view of the components being manipulated. Access covers shall be equipped with grasp areas or other means for opening them. The dimensions of access openings for arms, hands and fingers shall be no less than those shown in Figure 37. Allowance shall be made for the clearance of the operator's gloved or mittened hand, as appropriate, if the access is located externally and may require servicing under arctic conditions. If a hazardous condition, such as exposed conductors energized with dangerous voltages, exist behind the access, the physical barrier over the access shall be equipped with an interlock that will de-energize the hazardous equipment when the barrier is opened or removed. Where physical access is required, the following practices shall be followed in order of preference:

a. An opening with no cover unless this is likely to degrade system performance or safety.

MINIMAL TWO-HAND ACCESS OPENINGS WITHOUT VISUAL ACCESS

Reaching with both hands to depth of 6 to 19 25 inches:

Light clothing:	Width:	8" or the depth of reach*
	Height:	5"
Arctic clothing:	Width:	6" plus 3 4 the depth of reach
	Height:	7"

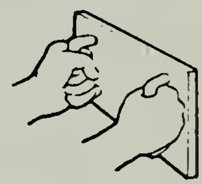


Reaching full arm's length (to shoulders) with both arms:

Width:	19.5"
Height:	5"

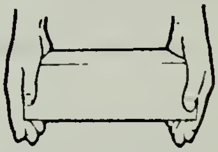
Inserting box grasped by handles on the front:

1 2" clearance around box, assuming adequate clearance around handles



Inserting box with hands on the sides:

Light clothing:	Width:	Box plus 4.5"
	‡ Height:	5" or 0.5" around box*
Arctic clothing:	Width:	Box plus 7"
	‡ Height:	8.5" or 0.5" around box*



* Whichever is larger.

‡ If hands curl around bottom, allow an extra 1.5" for light clothing, 3" for arctic clothing.

MINIMAL ONE-HAND ACCESS OPENINGS WITHOUT VISUAL ACCESS

	Height		Width		
Empty hand, to wrist:					
Bare hand, rolled:	3.75"	sq or dia			
Bare hand, flat:	2.25"	x	4.0"	or	4.0" dia
Glove or mitten:	4.0"	x	6.0"	or	6.0" dia
Arctic mitten:	5.0"	x	6.5"	or	6.5" dia
Clenched hand, to wrist:					
Bare hand:	3.5"	x	5.0"	or	5.0" dia
Glove or mitten:	4.5"	x	6.0"	or	6.0" dia
Arctic mitten:	7.0"	x	8.5"	or	8.5" dia
Hand plus 1" dia object, to wrist:					
Bare hand:	3.75"	sq or dia			
Gloved hand:	6.0"	sq or dia			
Arctic mitten:	7.0"	sq or dia			
Hand plus object over 1" in dia, to wrist:					
Bare hand:	1.75"	clearance around object			
Glove or mitten:	2.5"	clearance around object			
Arctic mitten:	3.5"	clearance around object			
Arm to elbow:					
Light clothing:	4.0"	x	4.5"	or	4.5" dia
Arctic clothing:	7.0"	sq or dia			
With object:	Clearances as above				
Arm to shoulder:					
Light clothing:	5.0"	sq or dia			
Arctic clothing:	8.5"	sq or dia			
With object:	Clearances as above				

MINIMAL FINGER ACCESS TO FIRST JOINT

Push button access:	Bare hand:	1.25" dia
	Gloved hand:	1.5" dia
Two finger twist access:	Bare hand:	object plus 2.0" dia
	Gloved hand:	object plus 2.5" dia

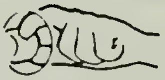


Figure 37. ARM AND HAND ACCESS DIMENSIONS

b. A sliding or hinged cap or door where dirt, moisture, or other foreign materials might otherwise create a problem.

c. A quick-opening cover plate if a cap will not meet stress requirements.

5.9.9.4.2 Whole Body Access. - See 5.7.8.3

5.9.9.5 Visual Access. - Where visual access only is required, the following practices shall be followed in order of preference:

a. An opening with no cover except where this might degrade system performance.

b. A transparent window if dirt, moisture, or other foreign materials might otherwise create a problem.

c. A break-resistant glass window if physical wear, heat, or contact with solvents would otherwise cause optical deterioration.

d. A quick-opening metal cover if glass will not meet stress or other requirements.

5.9.10 Fasteners

5.9.10.1 General. - The number and diversity of fasteners used shall be the minimum commensurate with requirements for stress, bonding, etc. Hand-operated fasteners shall be given preference; those requiring non-standard tools shall not be used.

5.9.10.2 Hinges and Tongue-and-Slot Catches. - Optimum use shall be made of hinges and tongue-and-slot catches to minimize the number of fasteners required.

5.9.10.3 Captive Fasteners. - Captive bolts and nuts shall be used in situations where dropping such items might cause damage to equipment or create a difficult or hazardous removal problem. Captive fasteners shall be provided for access covers requiring periodic removal. Captive, quick-opening fasteners shall be provided on cases and covers, except where equipment performance would be jeopardized thereby. Whenever feasible, the same type and size of fasteners should be provided for all cases and covers.

5.9.10.4 Size and Quantity. - If a hinged access panel or quick-opening fasteners will not meet stress, pressurization, shielding, or safety requirements, the minimum number of the largest screws consistent with these requirements shall be used.

5.9.10.5 External-Grip Head. - Whenever possible, an external-grip head shall be provided on bolts requiring high torques (to reduce the need to drill out bolts with damaged slots).

5.9.10.6 Accessibility. - The heads of mounting bolts and fasteners should be located on surfaces readily accessible to the technician.

5.9.10.7 Common Items. - Whenever possible, identical screw and bolt heads shall be provided to allow various panels and components to be removed with one type of tool. Combination bolt heads such as slotted hex head should be selected whenever feasible.

5.9.10.8 Number of Turns. - Fasteners for mounting assemblies and subassemblies shall require only one complete turn, provided that stress and load considerations are not compromised. When bolts are required, the number of turns needed to tighten and loosen them shall be minimized.

5.9.11 Unit Design for Efficient Handling

5.9.11.1 Rests and Stands. - Rests or stands on which units can be placed should be provided, including space for test equipment, tools, and manuals whenever feasible. When permitted by design requirements, such rests or stands shall be part of the basic unit, rack or console chassis.

5.9.11.2 Extensions. - Irregular, fragile, or awkward extensions, such as cables, wave guides, hoses, etc., shall be designed for easy removal from a unit before handling.

5.9.11.3 Weight

5.9.11.3.1 Lifting

5.9.11.3.1.1 Limits. - The weight limits in Table X shall be used as the maximum values in determining the design weight of items requiring one-man lifting, providing the item to be lifted is of convenient configuration (not more than 15" long, or 12" high) and handles or grasp areas conform to 5.9.11.4; however, the limits in Table X are not applicable for repetitive lifting. Double the weight limits in Table X shall be used as the maximum values in determining the design weight of items requiring two-man lifting, providing the item to be lifted is of convenient configuration, handles and grasp areas conform to 5.9.11.4, and the one-man limit, as stated above, is not exceeded for either man.

5.9.11.3.1.2 Labeling. - Items weighing more than the one-man lift values of Table X shall be prominently labeled with weight indication and lift limitation, i.e., mechanical or two-man lift. Where mechanical or power lift is required, hoist and lift points shall be provided and clearly labeled.

5.9.11.3.2 Carrying. - The limits of Table X are not applicable to tasks requiring carrying the item of equipment more than a few steps. (See 5.11.1)

TABLE X. DESIGN WEIGHT LIMITS

HEIGHT OF LIFT ABOVE GROUND	MAXIMUM WEIGHT OF ITEM
5 ft (152 cm)	35 lb (16 kg)
4 ft (122 cm)	50 lb (23 kg)
3 ft (91 cm)	65 lb (29 kg)
2 ft (61 cm)	80 lb (36 kg)
1 ft (30 cm)	85 lb (39 kg)

5.9.11.4 Handles and Grasp Areas

5.9.11.4.1 General. - All removable or carried units designed to be removed and replaced shall be provided with handles or other suitable means for grasping, handling, and carrying (where appropriate, by gloved or mittened hand).

5.9.11.4.2 Location. - Whenever possible, handles or grasp areas shall be located relative to the center of gravity of the unit to preclude swinging or tilting when lifted. They shall be located to provide at least 2 inches (50.8mm) of clearance from obstructions during handling.

5.9.11.4.3 Nonfixed Handles. - Nonfixed handles (e.g., hinged or fold-out) shall have a stop position for holding the handle perpendicular to the surface on which it is mounted and shall be capable of being placed into carrying position by one hand (where appropriate, by gloved or mittened hand).

5.9.11.4.4 Grasp Surface. - Where a unit's installation requires that its bottom surface be used as a handhold during removal or installation, a nonslip grasp surface (e.g., grooved or frictional) shall be provided.

5.9.11.4.5 Handle Dimensions. - Handles which are to be used with mittened, gloved, or ungloved hands shall equal or exceed the minimum applicable dimensions shown in Figure 38.

5.9.11.4.6 Handle and Grasp Area Force Requirements. - Force requirements to operate handle and grasp areas other than controls covered by paragraph 5.4 shall not exceed the values in Figure 14.

5.9.12 Mounting

5.9.12.1 General. - Units shall be designed so that they cannot be mounted improperly.

5.9.12.2 Tools. - Field removable units shall be replaceable by use of nothing more than common hand tools.

5.9.12.3 Removal. - Units should be removable along a straight or slightly curved line, rather than through an angle.

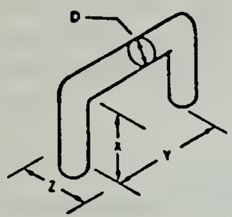
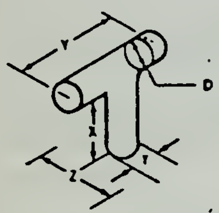
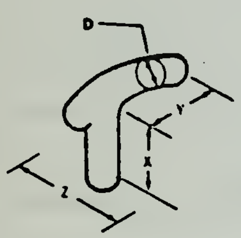
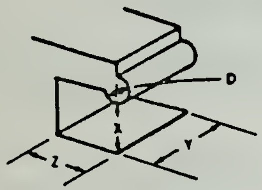
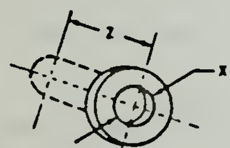
5.9.12.4 Alignment. - Guide pins or their equivalent shall be provided to assist in alignment during mounting, particularly on modules that are connectors themselves.

5.9.12.5 Coding. - All replaceable items shall be coded (i.e., keyed) so that it will be physically impossible to insert a wrong item. Coding by such means as color or labels shall identify the correct item and its proper orientation for replacement.

5.9.12.6 Rollout Racks, Slides or Hinges. - Units which are frequently pulled out of their installed positions for checking shall be mounted on rollout racks, slides, or hinges. Rollout racks should not shift the center of gravity to the extent that the entire rack or console falls forward. If this possibility exists, the console or rack shall be bolted to the mounting surface or attached to the bulkhead.

5.9.12.7 Limit Stops. - Limit stops shall be provided on racks and drawers which are required to be pulled out of their installed positions for checking or maintenance. The limit stop design shall permit convenient overriding of stops for unit removal.

5.9.12.8 Interlocks. - Where applicable, interlocks shall be provided to ensure disconnection of equipment that would otherwise be damaged by withdrawal of racks or drawers.

ILLUSTRATIONS	TYPE OF HANDLE	DIMENSIONS (in.) (Bare Hand) X	Y	Z	(Gloved Hand) X	Y	Z	(Mittened Hand) X	Y	Z
	Two-finger bar	1.25	2.5	3.0	1.5	3.0	3.0	Not Applicable		
	One-hand bar	2.0	4.5	3.0	3.5	5.25	4.0	3.5	5.25	6.0
	Two-hand bar	2.0	8.5	3.0	3.5	10.5	4.0	3.5	11.0	6.0
	T-bar	1.5	4.0	3.0	2.0	4.5	4.0	Not Applicable		
	J-bar	2.0	4.0	3.0	2.0	4.5	4.0	3.0	5.0	6.0
	Two-finger recess	1.25	2.5	2.0	1.5	3.0	2.0	Not Applicable		
	One-hand recess	2.0	4.25	3.5	3.5	5.25	4.0	3.5	5.25	5.0
	Finger-tip recess	0.75	-	0.5	1.0	-	0.75	Not Applicable		
	One-finger recess	1.25	-	2.0	1.5	-	2.0	Not Applicable		

Curvature of Handle or Edge:	Weight of Item	Diameter (minimum)	
	up to 15 lbs:	D - 1/4 in.	Gripping efficiency is best if finger can curl around handle or edge to any angle of 120 degrees or better.
	15 to 20 lbs:	D - 1/2 in.	
	20 to 40 lbs:	D - 3/4 in.	
	Over 40 lbs:	D - 1 in.	
	T-bar Post:	T - 1/2 in.	

Figure 38. HANDLE DIMENSIONS

5.9.12.9 <u>Braces</u>. - Hinged units shall be provided with a brace or other means to hold units in the "out" position during checking or maintenance.

5.9.12.10 <u>Rear Access</u>. - Sliding, rotating, or hinged units to which rear access is required shall be free to open or rotate their full distance and remain in the "open" position without being supported by hand.

5.9.12.11 <u>Lay-Out</u>. - Units shall be laid out so that a minimum of place-to-place movements will be required during checkout.

5.9.12.12 <u>Covers or Panels</u>. - Removal of any replaceable unit shall require opening or removing a minimum number of covers or panels.

5.9.12.13 <u>Frequency of Use</u>. - When it is necessary to place one unit behind another, the unit requiring most frequent access shall be most accessible.

5.9.12.14 <u>High Frequency Access</u>. - The physical arrangement of units and components shall be such that all high-failure items will be readily accessible for replacement without removing any non-failed components or units. Replaceable mechanical items shall be readily removable with common hand tools and simple handling equipment.

5.9.12.15 <u>Fasteners</u>. - Unit installation shall require a minimum of fasteners, both as to numbers and types.

5.9.13 <u>Conductors</u>

5.9.13.1 <u>Cables</u>. - Conductors shall be bound into cables and held by lacing tape per MIL-T-43435 or equivalent means.

5.9.13.2 <u>Coding</u>. - Cables containing individually insulated conductors with a common sheath shall be coded.

5.9.13.3 <u>Cable Clamps</u>. - Long conductors, bundles or cables, internal to equipment, shall be secured to the equipment chassis by means of clamps unless contained in wiring ducts or cable retractors.

5.9.13.4 <u>Length</u>. - Cables shall be long enough so that each functioning unit can be checked in a convenient place. Extension cables shall be provided where this is not feasible.

5.9.13.5 <u>Location of Test Cables</u>. - If it is essential that test cables terminate on control and display panels, the test receptacles shall be so located that the test cables will not interfere with controls and displays.

5.9.13.6 Access. - Cables shall be routed so as to be readily accessible for inspection and repair.

5.9.13.7 Susceptability to Abuse. - Cables shall be routed or protected in such a way that they may not be pinched by doors, lids, etc., walked on, used for hand holds, or bent or twisted sharply or repeatedly.

5.9.13.8 Cable Protection. - If it is necessary to route cables and wires through holes in metal partitions, the conductors shall be protected from mechanical damage or wear by grommets or equivalent means.

5.9.13.9 Identification. - Cables should be labeled to indicate the equipment to which they belong and the connectors with which they mate.

5.9.14 Connectors

5.9.14.1 Use of Quick Disconnect Plugs. - Plugs requiring no more than one turn, or other quick-disconnect plugs, shall be provided whenever feasible.

5.9.14.2 Keying. - Plugs shall be so designed that it will be impossible to insert a wrong plug into a receptacle whenever the possibility exists.

5.9.14.3 Identification. - Connecting plugs and receptacles shall be clearly identified by color, size, or equivalent means.

5.9.14.4 Alignment. Plugs or receptacles shall be provided with aligning pins or equivalent devices to aid in alignment and to preclude inserting in other than the desired position.

5.9.14.5 Aligning Pins. - Aligning pins shall extend beyond the plug's electrical pins to insure that alignment is obtained before the electrical pins engage.

5.9.14.6 Orientation. - Plugs and receptacles shall be arranged so that the aligning pins or equivalent devices are oriented in the same relative position.

5.9.14.7 Coding. - Plugs and receptacles shall have durable stripes, arrows, or other indications to show the positions of aligning pins or equivalent devices for proper insertion.

5.9.14.8 Spacing. - Connectors shall be spaced far enough apart so that they can be grasped firmly for connecting and disconnecting. Space between adjacent connectors will depend upon the size and shape of the plugs, but shall not be less than 1 inch (25.4mm), except where connectors are to be sequentially removed and replaced and one inch clearance is available in the plane perpendicula. to the remove/replace sequence line.

5.9.14.9 Testing and Servicing. - The rear of plug connectors shall be accessible for testing and servicing, except where precluded by potting, sealing, or other requirements.

5.9.14.10 Drawer Modules. - Drawer modules designed for "remove and replace" maintenance shall be provided with connectors mounted on the back of the drawer and mated with connectors in the cabinet to accomplish electrical inter-connection between the drawer, other equipment in the rack and external connectors, where feasible. Guide pins or equivalent devices shall be provided to aid in alignment.

5.9.14.11 Simplicity. - In electronic equipment, replacement items (e.g., modules and high-failure-rate components) shall normally be provided with simple plug-in connectors.

5.9.14.12 Disassembly and Adapters. - Disassembly of connectors for reasons of changing pin connections should be easily performed without special tools. When adapters are required, they shall be capable of being hand-tightened.

5.9.15 Test Points. - For purposes of this standard, test points shall be classified as defined in MIL-STD-415. Test provisions and marking shall be as specified in MIL-STD-415.

5.9.15.1 Adjustment. - Test points used in adjusting a unit shall be located close to the controls and displays used in the adjustment.

5.9.15.2 Trouble-Shooting. - Sufficient test points shall be provided so that it will not be necessary to remove subassemblies from assemblies to accomplish trouble-shooting.

5.9.16 Test Equipment

5.9.16.1 Storage. - Adequate storage space shall be provided within portable test equipment, its handling case, or lid to contain leads, probes, spares, manuals, and special tools, as required for operation.

5.9.16.2 Instructions. - Instructions for operating portable test equipment shall be provided on the face of the test equipment, in a lid, or in a special compartment. Where applicable, the instructions shall include a reminder to calibrate the equipment before using it.

5.9.17 Failure Indications and Fuse Requirements

5.9.17.1 Indication of Equipment Failure

5.9.17.1.1 Power Failure. - An indication shall be provided to reveal when power failure occurs.

5.9.17.1.2 Out-of-Tolerance. - Display shall be provided to indicate when equipment has failed or is not operating within tolerance limits.

5.10 DESIGN OF EQUIPMENT FOR REMOTE HANDLING

5.10.1 General

5.10.1.1 Compatibility. - Remote-handling tasks and equipment shall be planned and designed concurrently with the equipment and material to be handled by remote manipulation, so as to ensure their compatibility.

5.10.2 Characteristics of Equipment to be Handled Remotely

5.10.2.1 Alignment. - Self-alignment devices shall be provided for components which must be joined remotely.

5.10.2.2 Disconnect. - Quick-disconnect devices shall be provided to reduce remote-handling difficulties.

5.10.2.3 Fasteners. - All fasteners shall be captive and readily replaceable by remote-handling techniques.

5.10.2.4 Lock and Latching Mechanisms. - Each lock or latching mechanism shall be operable from a single point, have a positive catch, and provide a clear visual indication of the latch position.

5.10.3 Feedback. - Provision shall be made for transmitting information from remote work areas to the operator of the remote-handling system. Visual information shall be regarded as most critical, followed by kinesthetic, tactual, and auditory feedback.

5.10.4 Manipulators

5.10.4.1 Safety. - Power manipulators shall be provided with positive stops to prevent accidents.

5.10.4.2 Characteristics. - For tasks which require manipulative dexterity and load capacities of less than 20-25 pounds (9.1-11.3 kg), manipulators with the following characteristics should be provided:

a. Position control (i.e., zero-order control in which the operator's control output directly determines the machine output).

b. Mutual force reflection between control and effector.

c. Seven degrees of freedom in motion and force control (i.e., three for translation, three for rotation, and one for gripping).

5.10.4.3 Power Assist. - For tasks involving gross positioning of loads heavier than 25 pounds (11.3kg), electrically or hydraulically powered manipulators with rate control should be provided (i.e., the operator's control output directly determines the rate of change of the machine output).

5.10.5 Viewing Equipment

5.10.5.1 General. - A viewing system shall be provided which gives the operator of a remote manipulator adequate information with respect to the three spatial coordinates of the workspace (i.e., X, Y, and Z).

5.10.5.2 Direct Viewing. - When permitted by shielding requirements, provision shall be made for the operator to view the work directly through shielding windows.

5.10.5.3 Viewing Angle. - In order to avoid distortion, requirements shall be minimized for direct viewing of objects either near the viewing window or at line-of-sight angles at incidences greater than 60°.

5.10.5.4 Indirect Viewing. - Applicable viewing systems, such as closed circuit television systems, periscopes, and microscopes, shall be provided to supplement direct viewing, where required by specific remote-handling situations.

5.10.5.5 Coding. - Symbol- or pattern-coding should be used in preference to color-coding for television viewing.

5.10.5.6 Lettering. - Letters, numbers, and important details which must be viewed by means of television shall be light against a dark background. Glazed or reflecting surfaces shall be avoided.

5.10.5.7 Stereo Viewing. - The two images produced by a stereoscopic periscope shall not differ more than 0.25% in magnification, 1 degree in elevation, 15 minutes of angle in vertical alignment, and 1 degree in horizontal alignment. (The stereoscopic effect of a single lens stereo system is poor at powers less than 3X and exaggerated at powers greater than 3X.)

5.10.6 Illumination

5.10.6.1 Reflected Light. - Lighting provided in remote work areas shall be such that reflected light, as measured at the operator's work station (in direct viewing), will conform with the requirements of this standard, or as otherwise specified by the procuring activity.

5.10.6.2 Threshold Viewing. - Monochromatic lighting should be provided when viewing conditions are near threshold, when high magnification powers are required, or when the operator is required to view the work at high angles of incidence through refractive materials.

5.11 SMALL SYSTEMS AND EQUIPMENT

5.11.1 Portability and Man-Transportability. - Individual portions of equipment shall be designed so that, when carried, the weight of the load will be distributed through as many muscle groups as possible. Pressure should be avoided or minimized on sensitive areas, including large bloodvessels, nerves and areas lacking muscular padding. Design of load-carrying systems shall consider the weight and distribution of individual items to be carried by the user. See Table XI for weights of representative individual items.

5.11.1.1 Portability

5.11.1.1.1 Weight. - Individual portions of equipment may weigh up to 35 pounds (15.9 kg) if the load is balanced and is distributed over many muscle groups and it is not necessary for the system to maintain the pace of an infantry movement.

5.11.1.1.2 Lifting Aids. - When necessary, lifting aids shall be provided to permit a second man to assist the porter in placing the load on his body.

5.11.1.1.3 Configuration. - The load should be designed to permit freedom of movement. The shape of the load should be free of sharp edges or projections that may be harmful to the porter or snag on undergrowth. The shape and weight of the load should not interfere with:

a. The length of step.

b. Movements of the head.

c. The ability to raise and lower the load when going over obstacles.

d. The ability to see where the feet are placed when walking.

e. The ability to squat.

5.11.1.1.4 Two-Man Carry. - Where the load is designed for two-man carry, a combination of stretcher type handles and shoulder support should be used, if feasible.

5.11.1.1.5 Standardization. - Maximum use should be made of standard load carrying systems or components.

5.11.1.2 Man-Transportability. - Systems which include a requirement for man-transportability shall conform to the following provisions:

5.11.1.2.1 Weight. - Individual portions of equipment should be designed to weigh as little as possible if the system is to be manually transported by an individual on foot while maintaining pace with an infantry movement.

TABLE XI. WEIGHTS OF INDIVIDUAL ITEMS (Basic Rifleman)

ITEM		WEIGHT lb	(kg)
Uniform (see below)		11.1	(5.0)
Vest, fragmentation protective (medium)		8.5	(3.9)
M-56 equipment w/existence load (see below)		11.4	(5.2)
Poncho w/liner		3.0	(1.4)
Rifle, M16E1 w/full magazine		7.6	(3.4)
Magazines, M16, full (6) w/pouches (2)		5.7	(2.6)
Bayonet, M7 w/scabbard M8A1		0.9	(0.4)
Grenades, M26A1 (2)		2.0	(0.9)
Mask, protective w/case		2.7	(1.2)
	TOTAL	52.9	(24.0)
UNIFORM, SUMMER, TEMPERATE			
Helmet, steel w/liner and camouflage cover		3.67	(1.7)
Shirt and trousers, fatigue (medium)		2.50	(1.1)
Underwear, socks, belt, handkerchief		0.95	(0.4)
Boots, combat (size 10W)		3.95	(1.8)
	TOTAL	11.07	(5.0)
M-56 EQUIPMENT W/EXISTENCE LOAD			
Belt, pistol w/suspenders		1.67	(0.8)
Aid pocket w/pouch		0.20	(0.1)
Canteen and cup w/cover (full)		3.15	(1.4)
Entrenching tool, lt wt, w/cover		2.00	(0.9)
Pack, field		1.00	(0.5)
Match box, sunglasses and cigarettes or candy		0.32	(0.2)
Spoon, fork, knife		0.28	(0.1)
1 set underwear, 1 pr socks		0.66	(0.3)
Toilet articles		0.50	(0.2)
1/3 ration		1.63	(0.7)
	TOTAL	11.41	(5.2)

5.11.1.2.2 Lifting Aids

a. Units for which no back-packing aids are required shall be equipped with handles suitable for two-handed lifting and carrying.

b. The provisions of sections 5.9.11.4.1, 5.9.11.4.3, and 5.9.11.4.5 shall apply.

c. One-man back-packed loads over 44 pounds (20 kg) shall be designed, and, if necessary, provided with lifting aids to permit a second man to assist the porter in placing the load on his body.

5.11.1.2.3 Back-Packing Aids. - Back-packing aids shall be designed to distribute the load over as many muscle groups as possible by means of buttock and hip supports in addition to padded shoulder straps. Back-packing aids shall be designed to bring the center of gravity of the load as close to the porter's spine at the waistline as possible, without any part of the load actually contacting the body. Aids shall not produce laterally unbalanced loads, interfere with normal head movements, limit squatting, or interfere with walking or climbing over low obstacles.

5.11.1.2.4 Projections. - Loads shall be designed with a minimum of projections to prevent injury to personnel or entanglement in undergrowth. Covers or cases may be provided to meet this requirement, as specified by the procuring activity.

5.11.1.2.5 Standardization. - See 5.11.1.1.5.

5.11.2 Tracking

5.11.2.1 Gunner Environment. - Obscuration, shock and vibration should be so minimized as to permit resumption of tracking rapidly after firing, where required.

5.11.2.2 Crank Size. - The size of tracking cranks, where used, shall be a function of rotation speed required:

a. Maximum speed should be between 140 - 200 RPM.

b. Crank radius between 2.25 inches (57 mm) and 4.5 inches (114 mm).

(1) High RPM requirement: smaller crank radius.

(2) Low RPM requirement: larger crank radius.

5.11.2.3 Two Dimensional Tracking. - A single control, e.g., a joy stick or ball, should be used for two dimensional tracking rather than separate controls for each dimension.

5.11.2.4 Supports. - Where a joy stick is used for tracking, a hand, wrist or forearm support (as appropriate) should be provided.

5.11.2.5 Compatibility. - Movement of the tracking control shall be compatible with expected or conventional control movements.

5.11.3 Optical Instruments and Related Equipment

5.11.3.1 Visual Accommodation. - Any adjustment of the eyes beyond normal functional ability shall not be required.

5.11.3.2 Orientation. - Optical instruments shall be oriented so that they are presented to the operator at a comfortable viewing angle.

5.11.3.3 Exit Pupil Size. - In instruments requiring maximum illumination on the retina, the minimum exit pupil diameter for daylight viewing shall be 4 mm, for night time viewing, 8 mm.

5.11.3.4 Spacing. - Eyepieces shall be designed so that the operator's eye can be placed in the exit pupil. The exit pupil shall be located at least 12 mm away from the last glass surface.

5.11.3.5 Eye Relief. - When used with helmets, optical sights shall have a minimum eye relief of 15 mm.

5.11.3.6 Binocular Viewing. - Where continuous use of a sight under low levels of illumination will exceed one minute, the single optical train shall be provided with two eyepieces.

5.11.3.7 Magnification. - The eyepiece of instruments having a magnifying power of more than 4X shall be calibrated to accommodate the refracting qualities of the eyes of the individual user. (A single focus setting on instruments having a magnifying power of less than 4X provides a sufficient range of accommodation.)

5.11.3.8 Focusing. - Focusing eyepieces shall have a graduated scale calibrated in diopters; the range of adjustment shall be at least ± 4 diopters.

5.11.3.9 Binocular Instruments

5.11.3.9.1 Adjustability. - The interpupillary distance of instruments shall be adjustable from 50 to 76 millimeters.

5.11.3.9.2 Magnification. - Magnification differences to the two eyes shall not exceed 2%.

5.11.3.9.3 Balancing. - The amount of light emitted to the two eyes shall be balanced within 10%.

5.11.3.9.4 Ocular Pairing. - Oculars shall be paired to avoid size differences.

5.11.3.9.5 Weight. - Hand-held binoculars shall weigh no more than 2 pounds (0.9 kg).

5.11.3.10 Illuminated Sights and Reticles

5.11.3.10.1 Night Operations. - Illuminated reticles shall be provided for sights to be used during night operations.

5.11.3.10.2 Color. - Blue shall not be used as the color illumination for reticles or sights.

5.11.3.10.3 Dimming. - It shall be possible to gradually lower the brightness level of a sight until it is extinguished.

5.11.3.10.4 Illumination Level. - The illumination level of a sight (once an adjustment is made) shall remain fixed under all conditions of vibration.

5.11.3.10.5 Uniformity. - Illuminated sights shall be evenly illuminated by means of an opal diffuser or similar device.

5.11.3.10.6 Reticle Pattern. - The reticle pattern for illuminated sights should be a circle with tabs added to the side.

5.11.3.10.7 Reticle Lines. - Reticle lines should be 0.5 minutes (visual angle) or more in thickness. They shall be thin enough so as not to obscure targets, but thick enough to be easily seen. In any case their thickness should not exceed 2 minutes.

5.11.3.10.8 Format. - Line reticles should be used in preference to reticles containing one, two, or three central spots.

5.11.3.10.9 Cross or Circle. - A small cross or very small circle should be used in preference to a dot.

5.11.3.10.10 Simplicity. - Complicated reticle patterns should be avoided.

5.11.3.11 Eyecups and Headrests

5.11.3.11.1 Orientation. - Any optical instrument that requires steady orientation of the eyes shall be provided with a headrest and/or eyecups.

5.11.3.11.2 Material. - Eyecups shall be made of soft rubber or an equivalent material.

5.11.3.11.3 Light Exclusion. - Eyecups shall be designed to exclude stray light from entering the eyes.

5.11.3.11.4 Compatibility. - Eyecups, headrests, and eyepieces shall be compatible with helmets, gas masks, and other ancillary equipment.

5.11.3.11.5 Recoil. - In an optical instrument, the proper eye relief distance and exit pupil location shall beconsistent with the recoil characteristics of the weapon.

5.11.3.11.6 Energy Absorption. - A headrest or brow pad shall be used to absorb energy which would otherwise be absorbed by the operator's head.

5.11.3.11.7 Eyecup Design. - The radii of Figure 39 define a surface of revolution within which a satisfactory symmetrical eyepiece and cup must be designed if interferences with facial features are to be avoided. These should be applied to cushion forms when they are compressed to the maximum.

5.11.3.12 Optical Material Maintenance

5.11.3.12.1 Modular Design. - Optical equipment should be designed utilizing the modular concept, i.e., the interchangeability of optical assemblies within an instrument or optical modules that have multiple applications in equipment.

5.11.3.12.2 Positioning Aids. - Built-in aligning devices and other aids should be used wherever possible for ease of positioning optical assemblies within an instrument or optical modules that have multiple applications in equipment.

5.11.3.12.3 Quick Release. - Quick-release methods of removing optical instruments should be used wherever practical.

5.11.3.12.4 Collimation. - Optical instruments should be provided with built-in collimation features to allow field adjustment.

5.11.3.12.5 Purging and Charging. - Where periodic purging and charging of optical instruments are required, an instruction plate indicating time interval and pressure requirements shall be provided on the instrument.

5.11.3.12.6 Fittings. - Purging and charging fittings shall be accessible for required maintenance.

5.11.3.12.7 Openings. - Readily accessible openings should be provided to facilitate replacement, adjustment, and cleaning of reticles.

5.11.3.12.8 Light Bulb Access. - Light bulbs shall be located in an accessible location with sufficient hand clearance to allow removal and replacement by suitably clothed and equipped users with hand dimensions varying between 5th and 95th percentiles.

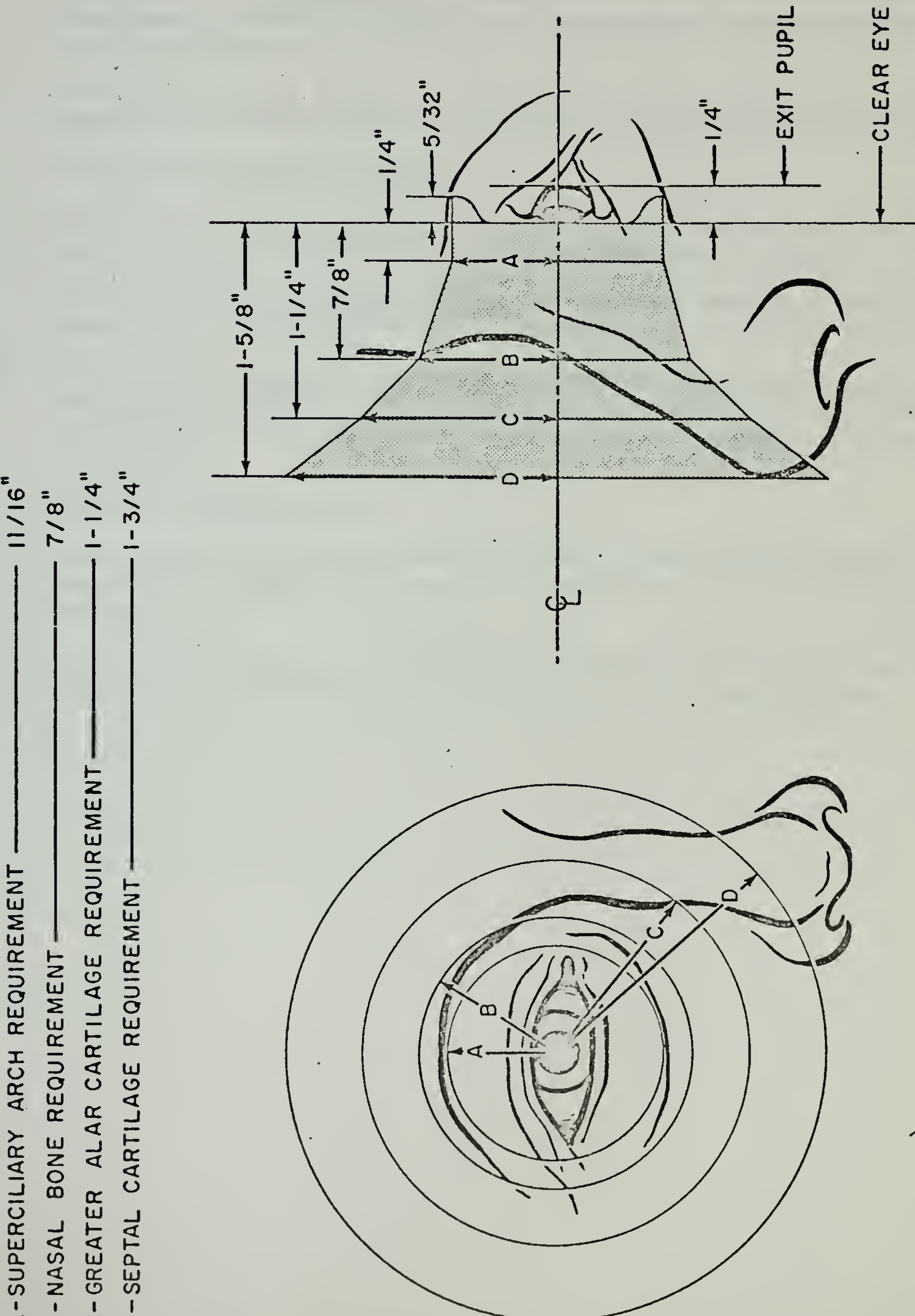


Figure 39. ANATOMICAL LIMITS ON AXIALLY SYMMETRICAL OCULAR METAL PARTS

5.11.3.12.9 Bulb Replacement. Light bulbs should be removable and replaceable without the removal or disassembly of other components of ancillary equipment.

5.11.3.12.10 Bulb Access. - The operator shall be able to remove and replace light bulbs from the front (operator end) of the optical device.

5.11.3.13 Boresight Knob Locks

5.11.3.13.1 Positive Locks. - Boresight knobs shall be provided with a positive lock. (The boresight settings shall not be changed when locking.)

5.11.3.13.2 Lock-Unlock Resistance. - Boresight knob locks shall not require more than 10 pounds (4.5 kg) resistance to lock and unlock.

5.11.3.13.3 Adjustment Operation. - Boresight adjustment knobs should be capable of being locked, unlocked and adjusted by suitably clothed and equipped users with hand dimensions varying between the 5th and 95th percentiles.

5.11.3.14 Sight Mounts.

5.11.3.13.1 Positioning. - Key and keyway, eccentric and keyway, and single dowel applications should be used for the final positioning of mounts.

5.11.3.13.2 Leveling. - Leveling vial supports should be strong enough to prevent the displacement of the bubble under slight pressure.

BIBLIOGRAPHY

1. Bilodeau, E.A. and Bilodeau, I.M., Principles of Skill Acquisition, Academic Press, 1969.

2. Caro, P.W., Hall, E.R., and Prophet, W.W., "Some Current Issues in the Design of Flight Training Devices," Commemorative Technical Journal, p. 133-140, November 1971.

3. Castle, J.E., Saklem, A.A., and Weiler, D.J., "The Shipboard Environment -- Past, Present and Future," Naval Engineers Journal, p. 102-117, June 1971.

4. Castle, J.E. and Weiler, D.J., The Need for an Open Systems Approach to Naval Ship Habitability Design, Naval Architects and Marine Engineers Transactions, 1973.

5. Chapanis, A., Research Techniques in Human Engineering, Johns Hopkins Press, 1962.

6. Department of Defense Military Specification MIL-H-46855A, Military Specification Human Engineering Requirements for Military Systems, Equipment and Facilities, 2 May 1972.

7. Department of Defense Military Standard MIL-STD-721B, Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety, 25 August 1966.

8. Department of Defense Military Standard MIL-1472A, Military Standard Human Engineering Design Criteria for Military Systems, 15 May 1970.

9. Department of the Navy OPNAV 10P23, Guide to the Preparation of Ship Manning Documents, 1971.

10. Erdman, R.L. and Neal, A.S., "Laboratory Versus Field Experimentation in Human Factors -- An Evaluation of an Experimental Self-service Airline Ticket Vendor," Human Factors, Volume 13, Number 6, p. 521-531, December 1971.

11. Fitts, P.M. and Jones, R.E., "Analysis of Factors Contributing to 460 'Pilot Error' Experiences in Operating Aircraft Controls," Selected Papers on Human Factors in the Design and Use of Control Systems, edited by H.W. Sinaiko, Dover, 1961.

12. Folley, J.D., and others, Human Factors Methods for System Design, The American Institute for Research, 1960.

13. Heffron, M.H., "The Naval Ship as an Urban Design Problem," Naval Engineers Journal, p. 49-64, June 1973.

14. Human Sciences Research Laboratory Report PTB 66-6, Considerations for Navy Planning and Systems Documentation: Some Exploratory Concepts, by J.A. Whittenburg and J.E. Wise, April 1966.

15. Kinkade, R.G. and Van Cott, H.P., Human Engineering Guide to Equipment Design, Government Printing Office, 1972.

16. Kline, M.B. and Lifson, M.W., Systems Engineering, Naval Postgraduate School, 1970.

17. Lazet, A. and Walraven, P.L., "Ergonomic Aspects of Automation in Navigation Bridges," Applied Ergonomics, Volume 2, Number 2, 1971.

18. Reference deleted.

19. Manion, R.C. and Cooper, L.J., Testing the OPTEVFOR Guidebook for the Collection of Human Factors Data, HRB-Singer, Inc., 1967.

20. Matheny, W.B., Patterson, G.W., and Evans, G.I., Human Factors in Field Testing, Life Sciences, Inc., 1971.

21. McKendry, J.M. and Harrison, P.C., Assessing Human Factors Requirements in the Test and Evaluation Stage of Systems Development, HRB-Singer, Inc., 1963.

22. Meister, David, Human Factors: Theory and Practice, Wiley, 1973.

23. Meister, David and Rabideau, G.F., Human Factors Evaluation in System Development, Wiley, 1965.

24. Myers, L.B., Carter, R.G., and Hostellar, R.S., Guidebook for the Collection of Human Factors Data, HRB-Singer, Inc., 1966.

25. New Developments Research Branch Report PRR 68-3, Human Factors Techniques in Deriving Personnel Requirements in Weapon System Development, by T.B. Malone, D.S. Gloss, J.W. Eberhard, Matrix Corporation, October 1967.

26. Naval Personnel Research and Development Laboratory Report WRM 70-41, Weapons System Personnel Requirements Evaluation Techniques, by J. L. Long, May 1970.

27. Naval Training Device Center Report 8030, Human Factors Inputs to the Training Device Design Process, by Alfred E. Smode, September 1971.

28. Naval Training Equipment Center Report 1795-06, Training Device Design: Human Factors Requirements in the Technical Approach, by Alfred E. Smode, August 1972.

29. Rook, L. W., Reduction of Human Errors in Industrial Production, Sandia Corporation, 1962.

30. Sandler, Curtis E., Human Engineering Deficiency Involvement in Naval Aircraft Mishaps Fiscal Years 1972 - 1973, Naval Safety Center, Norfolk, Virginia, May 1974.

31. Smode, Alfred E., Human Factors Inputs to the Training Device Design Process, Dunlap and Associates, 1971.

32. Swain, A. D., "Some Problems in the Measurement of Human Performance in Man-Machine Systems," Human Factors, Volume 6, Number 6, p. 687-700, December 1964.

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